SEFI

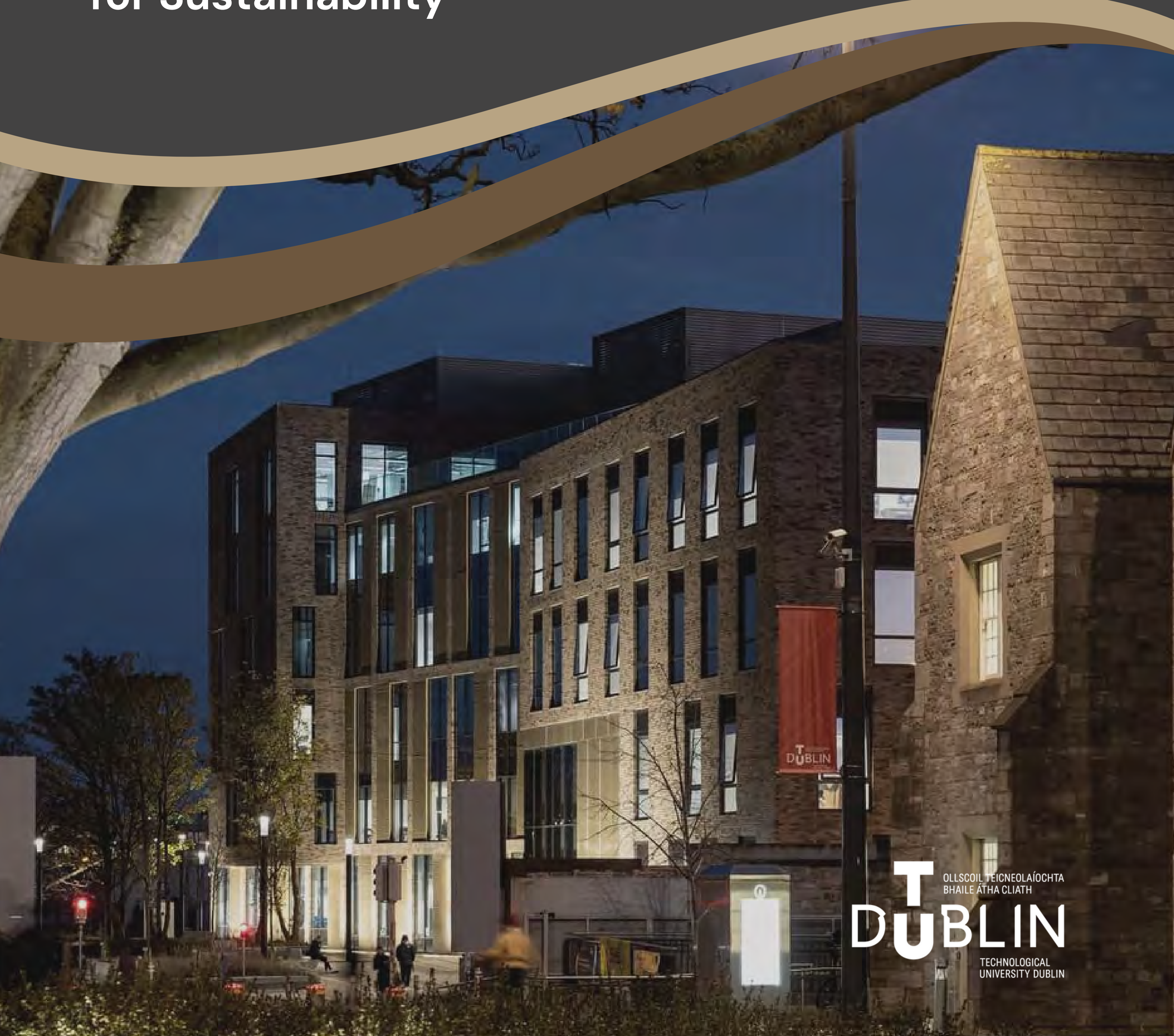
ANNUAL CONFERENCE
11-14 September 2023
TUDublin, Ireland

51ST ANNUAL CONFERENCE OF THE EUROPEAN SOCIETY FOR ENGINEERING EDUCATION

2023

PROCEEDINGS

Engineering Education for Sustainability



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Engineering Education for Sustainability

Co Organised by Technological University Dublin (TUDublin), Ireland and the European Society for Engineering Education (SEFI)

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European Society For Engineering Education – SEFI

The European Society for Engineering Education, SEFI, is the largest network of engineering education institutions and educators in Europe. It is an international non-governmental organisation established in Belgium in 1973. SEFI's aims and objectives are to contribute to the development and to the improvement of engineering education in Europe, to reinforce the position of the engineering professionals in society, to provide services to our members, to promote information about engineering education and improve communication and exchanges between teachers, researchers and students, to develop co-operation between educational engineering institutions and establishments of higher technical education, to promote co-operation between industry and engineering education actors, to be a link between our members and international organizations, and to promote the European dimension in higher engineering education.

SEFI serves as a European Forum to its members, composed of institutions of higher engineering education, academic staff and teachers, students, related associations, and companies in 48 countries.

The objectives of SEFI are encountered through a series of activities such as the Annual Conferences, Ad hoc seminars and workshops organised by SEFI's special interest groups, Taskforces on specific topics, the organization of the European Engineering Deans Conventions, Publications (incl. the European Journal of Engineering Education), European projects, Position papers, regular SEFI@work webinars, and European Engineering Educators podcast series.

A large part of SEFI's activities is dedicated to the cooperation with other major European associations and international bodies the European Commission, the UNESCO, the Council of Europe, or the OECD.

The SEFI Annual Conference is a scientific conference focused on Engineering Education and is the biggest event of this type in Europe. The conference is a unique opportunity for professors, students, industry and professional organisations to exchange their views and to meet their peers and create a European network of contacts.

SEFI is based in Brussels. For further information please visit our website: www.sefi.be or contact office@sefi.be.

Conference Welcome Address

GER REILLY

Co-Chair SEFI 2023 Conference

Head of Apprenticeships and Further Education
Technological University Dublin

Conference Location

TU Dublin is located in Dublin city and while it is a recognised leader in STEM disciplines, it also support a very large cohort of students in business, media, culinary arts, and the creative and performing arts in Ireland. The University is passionate about life-long learning and continuing professional development. TUDublin researchers and innovators are pioneers in science and technology discovery; they play active roles in informing policy and standards; and contribute to the creative life of Ireland.

The SEFI conference opens on Sunday September 10th with the Doctoral Symposium involving interaction between 35 PhD students and over 40 research mentors. On Monday September 11th the conference tracks commence. Overall the conference will provide delegates with a large number of events types and topical sessions involving:

- Plenary sessions involving 2 panel events and 2 keynote presentations
- Research Papers with 135 oral and 18 poster presentations
- Practice with 134 oral and 14 poster presentations
- A series of SIG (Special Interest Groups) Events Corporate workshops.

This will be one of the largest ever SEFI conference with over 575 delegates from 45 countries and it will give people a very positive perspective of the future of Engineering Education and Research.

On behalf of the Organising Committees of SEFI 2023 I am honoured and delighted to welcome you to Dublin for SEFI 2023. Céad míle fáilte romhaibh go léir chuig Ollscoil Teicneolaíochta Bhaile Átha Cliath le haghaidh SEFI 2023.

Conference Theme

How should we educate engineers to ensure that they are best prepared for a complex world?

We find ourselves at a critical junction in human history. Technology offers people access to a better standard of living than has ever before been possible and yet that same technology used in an unsustainable manner threatens our very existence through climate change and environmental catastrophe.

Engineers must be at the forefront of the move to a more sustainable world. Engineers must develop new technologies to address our current challenges as well as finding new ways to use old technology more sustainably. However, we cannot rely on technology alone to successfully address these challenges. The United Nations Sustainable Development Goals (UNSDG) make it clear that the challenge of sustainability affects every facet of human life including economic, political, social, and cultural. Whilst engineers will continue to be considered as masters of technology, they must also participate, in and make informed contributions to each of these facets in order to ensure that optimal policies are adopted, and effective solutions are developed and implemented.

How then should we educate engineers to ensure that they are best prepared to develop solutions for a complex, but sustainable world?

Engineering schools have not been blind to these challenges and have been striving to combine, within their curricula, excellent technical expertise with a broader understanding of sustainability and societal needs. SEFI 2023 asks that we share what we have learned already and to explore together what can yet be done.

Conference Topics at SEFI2023

1. Addressing the challenges of Climate Change and Sustainability
2. Embedding Sustainability and Ethics in the Curriculum
3. Engineering Skills and Competences, Lifelong Learning for a more sustainable world
4. Equality Diversity and Inclusion in Engineering Education
5. Education about and education with Artificial Intelligence
6. Engagement with Society and Local Communities
7. Engagement with Industry and Innovation
8. Mentoring and Tutoring
9. Fostering Engineering Education Research
10. Virtual and Remote education in a post Covid world
11. Innovative Teaching and Learning Methods
12. Fundamentals of Engineering: Mathematics and the Sciences
13. Built Environment and Architecture Education
14. Recruitment and Retention of Engineering Students
15. Curriculum Development
16. Contributions on other topics in Engineering Education

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ANNUAL CONFERENCE
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Plenary Information

ANNUAL CONFERENCE
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Plenary 1

Recent Trends in Engineering Education Research - How to Support Change and Inclusive Futures in Engineering Education?

Convened and Moderated by **Professor Aditya Johri** with Panel Members; **Dr Diana Martin, Professor Kristina Edström, Professor John Mitchell and Professor Bill Williams**

Summary

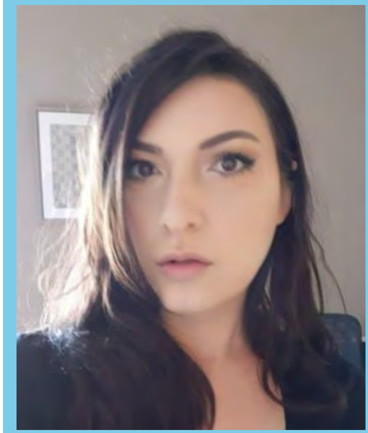
The panel aims to bring to the attention of the SEFI community recent trends in engineering education research (EER) and discuss their role in supporting change. Prompted by the launch of the *International Handbook of Engineering Education Research,* panelists will discuss ways to document the teaching and implementation of engineering education via research and how research can contribute to strengthening engineering education and promoting sustainable change. The panelists will discuss issues such as:

- What constitutes a contribution to the field of engineering education research? What counts as knowledge? Who gets to create and disseminate new ideas and knowledge?
- How does the community translate new knowledge based on EER to actual practice of improving education?
- What is the status of EER in engineering programs in Europe? How can EER gain legitimacy and improve its visibility or status in engineering programs?
- What can we say about where the field needs to go next? What is missing?

Professor Aditya Johri

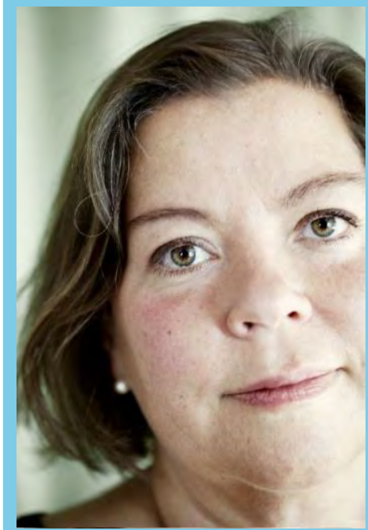
Aditya Johri is Professor of Information Sciences & Technology and Director of Technocritical Research in AI, Learning & Society Lab (trailsLAB) at the College of Engineering and Computing at George Mason University, USA. He studies how technology shapes learning across formal and informal settings and the ethical implications of using technology. He publishes broadly in the fields of engineering and computing education, educational technology, and computer-supported collaborative work and learning and is the editor of International Handbook of Engineering Education Research (IHEER) (Routledge/ 2023). His research has been recognized with several best paper awards and his co-edited volume, the Cambridge Handbook of Engineering Education Research (CHEER), received the 2015 Best Book Publication Award from Division I of AERA. He served as a Fulbright-Nokia Distinguished Chair in ICT at Aalto University, Finland (2021) and is a past recipient of the NSF Early Career Award (2009). He received the University Teaching Excellence Award (2002) and Mentoring Excellence Award (2022) for undergraduate research at George Mason University. He was awarded a Ph.D. in Learning Sciences & Technology Design (2007) from Stanford University, Palo Alto, CA. More information is available at: http://mason.gmu.edu/~johri

Dr Diana Martin



Diana Adela Martin has a PhD in Engineering Education (TU Dublin) and is currently an educational researcher at TU Eindhoven. Her research examines how ethics, sustainability, and societal responsibility are taught and implemented in the engineering curricula, with a focus on real-life educational settings. In Romania, Diana founded an educational NGO (2008-2015) which fostered cooperation between academia and the private sector, and in 2015 was selected by the European Forum Alpbach as one of Europe's innovators in tackling inequality in education. Diana is the co-chair of the Ethics Special Interest Group of SEFI – The European Society for Engineering Education (2022-25) and the Europe board representative in REEN – The Research Network in Engineering Education (2022-26). Diana serves also as an Associate Editor for the *European Journal of Engineering Education*, *Science and Engineering Ethics* and the *International Handbook of Engineering Education Research*.

Professor Kristina Edström



Kristina Edström is Associate Professor in *Engineering Education Development* at KTH Royal Institute of Technology, and Editor-in-Chief of the *European Journal of Engineering Education*. She is active in educational development and research at KTH, in Sweden and internationally. Her research takes a critical perspective on the *why*, *what* and *how* of engineering education development.

Professor John Mitchell

John E. Mitchell is Professor of Communications Systems Engineering in the UCL Department of Electronic and Electrical Engineering and Co-director of the UCL Centre for Engineering Education. Between 2012 and 2016 he was on secondment to the UCL Engineering Sciences Faculty office, where he led the introduction of the Integrated Engineering Programme, a major revision of the curriculum across the engineering faculty. In 2018 he was part of the team was awarded the HEA Collaborative Award for Teaching Excellence (CATE). He has published widely on curriculum development, active learning and issues of diversity within engineering education. From 2015 to 2022 he was Vice-Dean Education of the UCL Faculty of Engineering Sciences. Professor Mitchell is a Chartered Engineer, Fellow of the Institution of Engineering and Technology (IET), Senior Member of the Institute of Electrical and Electronics Engineers (IEEE), Principal Fellow of the Higher Education Academy, President of the UK's Engineering Professors' Council, Vice-President Publications of the IEEE Education Society and was until recently a Member of the Board of Directors of the European Society for Engineering Education and Editor-in-Chief of the IEEE Transactions on Education.

Professor Bill Williams

Bill Williams is a researcher at CEGIST, the Centre for Management Studies of Instituto Superior Técnico, University of Lisbon, is *Professor Jubilado* of Setúbal Polytechnic Institute, Portugal, and Adjunct Senior Research Fellow at TUDublin, Ireland. He originally trained as a chemist at UCC, National University of Ireland and went on to work in education in Ireland, UK, Eritrea, Kenya, Mozambique, and Portugal. He serves as an associate editor of the European Journal of Engineering Education (EJEE) published by the European Society for Engineering Education (SEFI) and senior associate editor for the Journal of Engineering Education (JEE) published by the American Society for Engineering Education (ASEE). He was lead editor of "Engineering Practice in a Global Context, Understanding the Technical and the Social" an edited volume published by Routledge in 2014. He is a founder member of the Portuguese Society for Engineering Education (SPEE) and is active in SEFI special interest groups on Engineering Education Research and on Diversity and Inclusion.

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Plenary 2

Which Engineering is Needed for AI?

A plenary session convened by **Mr Alex Tarchini** (Mathworks)and moderated by members of the **Board of European Students of Technology (BEST) and European Students of Industrial Engineering and Management (ESTIEM)** with Panel Invitees; **Xavier Fouger** (Dassault Systèmes), **Susannah Cooke** (ANSYS), **Marco Rossi** (MathWorks), **Martin Koczmann** (Siemens), **Susie Ye** (Bentley) and **Jorge Lopez** (Airbus)

Summary

Artificial Intelligence (AI) has become one of the biggest drivers of technological change, impacting industries and creating entirely new opportunities.

There is a significant demand in the industry for individuals who possess the skills required to deploy scalable AI applications. Companies of all sizes (from small start-ups to large organizations) hire AI engineers to build machine learning products. Although you do not need to be an expert or practitioner of AI to develop an AI vision and strategy, understanding AI and related subject matter areas is critical to making informed decisions.

We asked panelists, to elaborate and share with the audience about their company position and:

- to outline **how AI is transforming** the industries served by their companies;
- to report about the **"AI needs"** that their industrial customers are expressing: what skills (technical and soft) are requested to embed AI in engineering design?
- To offer **ways engineering universities could match these needs** (Dual Learning, Micro Certificates, PBL, …)

Xavier Fouger

Xavier Fouger is an Industrial Engineer, former Science Attaché for the French embassy in Vienna, Xavier joined Dassault Systemes in 1990 to develop innovation processes for automotive manufacturers in Germany and Korea. He founded the corporate organization in charge of academia, designed learning initiatives for secondary and vocational education in the USA, Malaysia, Canada and France and deployed learning centres in universities in India, China, Brazil, Mexico, South Africa, Kenya, Ivory Coast, Vietnam and Argentina. He created Dassault Systemes' Learning Lab to collaborate with university in educational innovation within projects funded by US and European agencies, focusing on practices enabled by digital technologies: social innovation, precision agriculture, Internet of Things, Virtual Twins, Additive Manufacturing, Collaborative Robotics, Smart Farm/Factory /City/Building and Model Based Systems Engineering. He currently works on industry-inspired learning centres, educational government programs and collaboration with engineering education societies.

Susannah Cooke

Susannah Cooke is a Senior Product Manager at Ansys, managing Ansys Academic software.

She works with universities to ensure that Ansys tools can be deployed to best effect in teaching and research. She holds an MEng and DPhil in Mechanical Engineering from the University of Oxford, where her doctoral thesis focused on fluid flow around tidal turbine arrays. She has also previously worked for the UK's research funding agency, UKRI, and she began her engineering career in railway maintenance."

Martin Koczmann

Martin Koczmann is the Academic Project Manager for the EMEA (Europe, Middle East, and Africa) region at Siemens PLM Software. In this role, he manages academic relations in the EMEA Zone and helps develop and support Siemens PLM Software's academic partner community.

Engagement in dialogues on industry trends, academic best practices, and digital transformation is an integral part of this role. These discussions take place with educators and other professionals, creating a rich exchange of ideas and experiences. There's a significant focus on preparing the next generation of digital talent, with a particular emphasis on the contexts of emerging technologies such as Industry 4.0 and Artificial Intelligence. The goal is to ensure that the future workforce is not only proficient in these technologies but also skilled at integrating them into practical applications that drive industry growth and innovation, while also considering sustainability.

Susie Ye

Susie Ye is an Education Program Manager from Bentley Systems, an infrastructure engineering software company. Being a technology enthusiast in the engineering industry, Susie loves discovering emerging engineering technologies and how they can contribute to solving real-world problems.

Being an Education Program Manager, her goal is to support young professionals upskill and unlock new career opportunities by providing industry engineering software and expertise to education institutions and engineering students. Having been working in manufacturing, tech and AEC industry, Susie finds herself constantly learning new technologies & innovations and privileged to have benefited from many industry mentors' help. During the learning process, Susie understood the need to develop new talents for the engineering industry in order to build a better world, as well as unlock the power of engineering education that enables talent development.

Marco Rossi

Marco Rossi is member of the MathWorks Academia Team and supports lecturers and researchers in the use of MATLAB and Simulink for teaching and research.

Since 2020, Marco runs curriculum development projects in Hungary, Croatia, Czech Republic, Turkey, South Africa, and many other Universities. Marco graduated in Aeronautical Engineering from La Sapienza in Rome. Since 2015 he worked as Assistant Researcher at TU Dresden in Germany, where in 2019 he obtained a PhD in Mechanical Engineering due to his work on modeling and simulation of soft materials. Marco taught several courses during his academic experience including statics and intelligent materials.

Jorge Lopez

Jorge Lopez is currently working at Airbus, at the AI connectivity lab in Issy-Les-Moulineaux, in the Parisian region. Jorge holds a Ph.D. in Computer Science from Paris-Saclay University. He possesses both academic and industrial experience, having worked at companies such as IBM and Huawei, as well as having held various postdoctoral research appointments. Currently, at Airbus, Jorge serves as an applied researcher, focusing on solving existing problems and proposing novel solutions in the domains of computer science and artificial intelligence.

Plenary 3

Interdisciplinary Projects – Moving from Transfer to Transformation in Learning

A Keynote Delivered by **Professor Anette Kolmos**

Summary

In the PBL communities, we have always argued that the deep learning in the projects would compensate for the lack of knowledge from taught courses by the students' ability to transfer knowledge to new areas. Within the disciplinary discourses, this has proved to be valid as the transfer of learning works within the same language and disciplinary thinking and the projects share similarities. However, we have learned that in an interdisciplinary context, where students are to transform their experiences from a disciplinary to an interdisciplinary context, the students do experience difficulties in leading and managing their projects.

This keynote will be based on results from the research project funded by Poul Due Jensen Foundation on interdisciplinarity and problem- and project-based learning (PBL). Key concepts in interdisciplinary types of projects will be presented together with research findings on students learning experiences. These findings are leading to a discussion on transfer and transformation in engineering learning – both in terms of scientific knowledge and generic competencies. The main message is that in order to facilitate interdisciplinary and flexible learning, the engineering curricula needs to be built on a higher degree of transformation and variation.

Professor Anette Kolmos

Anette Kolmos is Professor in Engineering Education and PBL, Founding Director (Director 2014-2023) for the UNESCO category 2 Centre: Aalborg Centre for Problem Based Learning in Engineering Science and Sustainability. She was Chair holder for UNESCO in Problem Based Learning in Engineering Education, Aalborg University, Denmark, 2007-2014. Guest professor at KTH Royal Institute of Technology 2012-2017. President of SEFI 2009–2011 (European Society for Engineering Education). Founding Chair of the SEFI-working group on Engineering Education Research. Was awarded the IFEES Global Award for Excellence in Engineering Education, 2013 and the SEFI fellowship in 2015.

During the last 20 years, Dr. Kolmos has researched the following areas, primarily within Engineering Education: gender and technology, project based and problem- based curriculum (PBL), change from traditional to project organized and problem- based curriculum, development of transferable skills in PBL and project work, and methods for staff development. She is Associate Editor for the European Journal of Engineering Education. She has been supervising more than 20 PhD students and has more than 310 publications. She has been member of several organizations and committees within EER, national government bodies, and committees in the EU.

Plenary 4

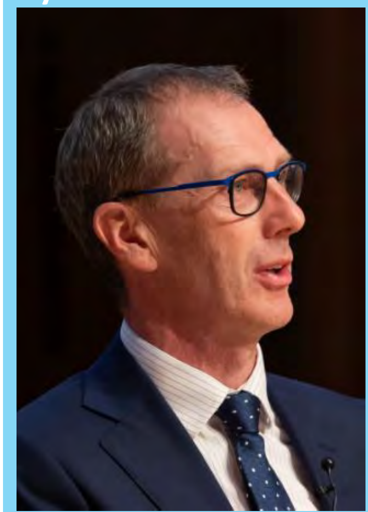
Contemporary Landscape, Drivers and Developments in Engineering Education for Sustainability

A Keynote Delivered by **Professor Edmond Byrne**

Summary

The 'landscape' around sustainability education in engineering has continued to evolve. Engineering education for sustainability largely emerged originally out of environmental engineering imperatives, though more recent developments have considerably broadened the scope of 'sustainability' teaching in professional engineering programmes. This has implications for associated curriculum developments as well as having pedagogical implications. Principal drivers for these developments emanate from the evolving requirements of professional engineering bodies internationally. These drivers have been supported and supplemented by an enhanced sense of urgency in the wake of the impacts of an unsustainable societal construct (e.g. the consequences of accelerated climate change, biodiversity loss, energy and food imperatives, etc.), as well as broader drivers such as around university policy, industry expectations for graduate attributes, and evolving societal imperatives. Having reflected on the above, some specific examples of how engineering education for sustainability may be incorporated into the curriculum are considered.

Professor Edmond Byrne



Edmond Byrne is Chair Professor of Process and Chemical Engineering at University College Cork. He is programme director on the BE(Hons)/ME in Process & Chemical Engineering. The programme won the Sustainability Teaching Award (2016) from the Institution of Chemical Engineers (IChemE). His research interests include engineering education for sustainable development, for which he has published widely, and transdisciplinary approaches to sustainability transformation, on which he has co-edited two books (Transdisciplinary Perspectives on Transitions to Sustainability, Routledge, 2017; Metaphor, Sustainability, Transformation; Transdisciplinary Perspectives, Routledge, 2021). He chaired the 10th Engineering Education for Sustainable Development conference (EESD2021), hosted at University College Cork in 2021.

Doctoral Symposium Report

SEFI ANNUAL CONFERENCE
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THE DOCTORAL SYMPOSIUM IN ENGINEERING EDUCATION RESEARCH AT SEFI 2023

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Conference Key Areas: *Fostering Engineering Education Research*
Keywords: *Engineering Education Research, doctoral education, networking*

ABSTRACT

The 7th SEFI Doctoral Symposium in Engineering Education Research, held at the campus of Technological University Dublin on Sunday, September 10th, preceded the SEFI 2023 Annual Conference. In all, 37 Ph.D. researchers attended, which is a record number for this event. They came to share and further probe their Ph.D. research topics and plans of study and to strengthen and extend their professional networks. During this full and intense day, 27 established scholars provided the Ph.D. researchers with personal feedback and ideas regarding their research. The highlight, according to the Ph.D. student participants, was the warm and enthusiastic reception they received from the well-established seniors of the global engineering education research community. Although SEFI is a European organization, the Ph.D. researchers and senior advisers who attended travelled to Ireland for this event from Africa, Australia, and South and North America, and from all over Europe.

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1 INTRODUCTION

1.1 The Role of the Doctoral Symposium in Engineering Education Research

Engineering education research (EER) is an emerging and expanding field, and it is now possible to pursue doctoral education in many institutions, in Europe as well as in other parts of the world. As in any research field, PhD students can benefit greatly from getting to know the leading scholars. This is however particularly true in EER since many PhD supervisors are educational champions with a background in engineering subjects, who are not themselves trained in educational research. It is also common that a PhD student is the only one in their university working on this topic. In such cases, it means a lot to have a supportive network beyond one's own environment (Edström et al., 2018). It is against this background that SEFI organises a Doctoral Symposium in conjunction with its annual conference. Prior to this year, the DS has been held the day before SEFI 2016 in Tampere, 2018 in Copenhagen, 2019 in Budapest, 2020 online from Twente, 2021 online from Berlin, and 2022 in Barcelona.

The objective of this paper is to document and share insights from the 7th SEFI Doctoral Symposium in Dublin 2023. The paper explains the design of the program and discusses recruitment of participants – both the doctoral students and experienced researchers. It proceeds to present some of the rich materials that was created and captured, including introductions, literature tips and advice from seniors and reflections from all participants. Finally, some reflections are made.

1.2 The SEFI Doctoral Symposium 2023

As in previous SEFI conferences, this year's Doctoral Symposium (DS) was held as a full-day pre-conference event on the Sunday preceding the conference.

The DS is fully interactive and uses a variety of formats to create an enriching experience:

- Short (one-minute) pitches by the seniors, so the early career researchers can familiarize themselves with well-established researchers
- Discussions in small groups focusing on each student's Ph.D. project (up to 30 minutes per student)
- Speed-dating activities to grow each participant's network
- Presenting (one-minute) take-home-messages, to ensure that valuable lessons are learnt and shared

1.3 Doctoral Student Participants

As in previous years, Ph.D. students were invited to submit an application in the form of an extended abstract, including:

- *A general introduction* (about their background and interest in EER)
- *An outline of their research* (an elevator pitch, along with identification of their research interest, thesis title, supervisors, current work),
- *Reflections* (their current questions, challenges, dilemmas, wishes, ambitions),
- *Preferences for networking* (at SEFI2023, and for keeping in touch after the conference).

The organising team, who (with some slight changes) has worked together on this event over the years, was delighted by the high number of applicants applying to attend in 2023. Much of the work submitted in 2023 was well developed and 40 proposals were accepted; however, due to visa complications three candidates were prevented from making the trip. Ultimately, 37 PhD students attended for the full day.

They represented 15 countries in four continents: Aruba, Australia, Belgium, Denmark, Finland, Germany, Ireland, Lithuania, the Netherlands, Norway, South Africa, Spain, Sweden, the UK, and the USA.

1.4 Senior Participants

To provide the Ph.D. researchers with feedback, coaching, and guidance, a diverse group of well-established senior participants was recruited. The organisers aim for a ratio of normally three juniors being coached by two seniors in focused sessions during the day. This has proven an optimal ratio for ensuring diverse but lively and targeted feedback for juniors.

The willingness – even eagerness – of the seniors to participate in this event was nothing short of remarkable. Seniors volunteer their time to travel to SEFI a day early and dedicate an entire Sunday to the event. Despite this, there was palpable enthusiasm among the seniors to participate, and almost every invitation that was issued was also accepted. This year 27 established scholars came to serve as senior advisors, including the organising team (the four authors of this paper). The senior participants and organisers travelled to the DS from Australia, Belgium, Denmark, Ireland, the Netherlands, Portugal, South Africa, Sweden, the UK, and the USA.

1.5 Group Formation

The core of the symposium consisted of group activities in which doctoral students and seniors worked together. This year, seven groups were formed, each containing four doctoral students and two to three senior participants. The groups were composed taking into account a balance between diversity and similarity regarding years of experience, research interests – both in terms of topics and methods, university, and country. The group formation was sent out to all participants in advance, together with a compilation of all extended abstracts. The instruction was to prepare by reading the abstracts of the doctoral students, at least the ones in their own group. The groups were formed a week in advance, with a few last-minute changes due to visa cancellations.

1.6 Event Outline

The program was designed to accommodate lively and deep discussions between Ph.D. researchers and experienced researchers. Group activities were the focus, and these were interspersed with plenary sessions:

09:00-09:30	Arrival, coffee & tea
09:30-10:00	Introductions and Instructions for the Day
10:00-12:00	First Group Session
12:00-13:00	Lunch
13:00-14:30	Speed Dating
14:30-15:10	Second Group Session
15:10-15:30	Refreshment Break
15:30-16:30	Plenary Report (Take-Home Messages: <1 Minute Per Person)
16:30-17:00	Final Reflections

2 CAPTURING THE DISCUSSIONS

2.1 Getting to Know the Experienced Researchers

Before the Doctoral Symposium, the senior participants were asked to submit some reading tips for the doctoral students. The first question was: *If a doctoral student* *wanted to read something by you, what would you recommend and why?* In response, the seniors mentioned the following selection of their own work (in alphabetical order):

Una Beagon

My PhD thesis - just to show the layout of chapters and the depth in which you have to go into to satisfy your examiners. It's important to know what is expected in the PhD.

- Beagon, U. (2021) A Phenomenographic Study of Academics Teaching on Engineering Programmes in Ireland: Conceptions of Professional Skills and Approaches to Teaching Professional Skills, Doctoral Thesis, TU Dublin, 2021. https://arrow.tudublin.ie/engdoc/125/

Jonte Bernhard

Quality in engineering education research (EER):

- Bernhard, J., & Baillie, C. (2016). Standards for quality of research in engineering education. *International Journal of Engineering Education, 32*(6), 2378-2394.

The relationship between "pure" engineering research and EER:

- Bernhard, J. (2015). Engineering education research as engineering research. In S. Hyldgaard Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, & B. Newberry (Eds.), *International perspectives on engineering education: Engineering education and practice in context, Volume 1* (pp. 393-414). Springer.

How engineering thinking can, indeed, improve the methods of EER:

- Carstensen, A.-K., & Bernhard, J. (2019). Design science research – a powerful tool for improving methods in engineering education research. *European Journal of Engineering Education, 44*(1-2),85-102.

Tom Børsen

If you are interested in curriculum development and interdisciplinary:

- Karadechev, P., Petersen, L. S., & Børsen, T. (2021). *Interdisciplinary competencies in the study program of Techno-Anthropology.* Aalborg University Press.

If you are interested in engineering ethics education:

- Børsen, T. Serreau, Y., Reifshneider, K., Baier, A., Pinkelman, R., Smetanina, T., & Zandvoort, H. (2021). Initiatives, experiences and best practices for teaching social and ecological responsibility in ethics education for science and engineering students. *European Journal of Engineering Education, 46*(2), 186-209.

Jenni Case

This was my attempt to try and understand how the curriculum within which I worked had come to be. This is not only a national but also a global context. There is huge potential in looking at these matters comparatively.

- Case, J. M. (2017). The historical evolution of engineering degrees: competing stakeholders, contestation over ideas, and coherence across national borders. *European Journal of Engineering Education, 42*(6), 974-986.

Shannon Chance

This is a comparison of two similar methodologies, with examples of how they're done.

- Chance, S., Duffy, G., & Bowe, B. (2020). Comparing grounded theory and phenomenology as methods to understand lived experience of engineering educators implementing problem-based learning. *European Journal of Engineering Education, 45*(3), 405-442.

I'm also quite proud of this lesser-known work:

- Chance, S., Marshall, J., & Duffy, G. (2016). Using architecture design studio pedagogies to enhance engineering education. *International Journal of Engineering Education, (32)*1B, 364-383.

Tinne De Laet

My latest publication focusing on metacognition for physics problem solving:

- Sijmkens, E., De Cock, M., De Laet, T. (2022). The Disciplinary Learning Companion: The Impact of Disciplinary and Topic-Specific Reflection on Students' EC-TEL 2022. *Lecture Notes in Computer Science, vol 13450*. Springer, Cham.

Inês Direito

Emotions in engineering education is an emerging research field:

- Lönngren, J., Direito, I., Tormey, R., & Huff, J. (2023). Emotions in engineering education. In A. Johri (Ed.), *International Handbook of Engineering Education Research* (pp. 156-182) Routledge.

Xiangyun Du

- Lyngdorf, N. E. R., Du, X., & Lundberg, A. (2023). First-year engineering students' learner agency sources in a systemic PBL environment: a Q study. *European Journal of Engineering Education*, 1-18.

Kristina Edström

This paper was such a joy to write – it changed me. I wish all of you to find your own compelling curiosity and your own voice.

- Edström, K. (2018). Academic and professional values in engineering education: Engaging with history to explore a persistent tension. *Engineering Studies, 10*(1), 38-65.

Cindy Finelli

- Finelli, C. J., Daly, S. R., & Richardson, K. M. (2014). Bridging the research-to-practice gap: Designing an institutional change plan using local evidence. *Journal of Engineering Education, 103*(2), 331-361.

David Knight

We need to talk about structural issues far more in engineering education.

- Knight, D. B., Grohs, J. R., Bradburn, I. S., Kinoshita, T. J., Vaziri, S., M. Matusovich, H., & Carrico, C. (2020). Illuminating inequality in access: Variation in enrollment in undergraduate engineering programs across Virginia's high schools. *Journal of Engineering Education, 109*(4), 665-684.

Greet Langie

- Craps, S., Pinxten, M., Knipprath, H., & Langie, G. (2022). Different roles, different demands. A competency-based professional roles model for early career engineers, validated in industry and higher education. *European Journal of Engineering Education, 47*(1), 144-163.

Joyce Main

- Main, J.B., Wang, Y. & Tan, L. (2021). The career outlook of engineering PhDs: Influence of postdoctoral research positions on the attainment of tenure track faculty positions and academic salaries. *Journal of Engineering Education, 110*(4): 977-1002.

Diana Adela Martin

The paper might be of interest if you work on ethics and sociotechnical aspects or if you are collecting data from multiple sources for your PhD:

- Martin, D.A., Conlon, E. & Bowe, B. (2021). A Multi-level Review of Engineering Ethics Education: Towards a Socio-technical Orientation of Engineering Education for Ethics. *Science and Engineering Ethics 27*, 60.

Abel Nyamapfene

This was my first serious foray into engineering education research. It took me several review cycles during which the ever-so-patient reviewers gradually taught me that a paper needs to have at least a study aim or better still a research question….

- Abel Nyamapfene (2010). Does class attendance still matter?, *Engineering Education, 5*:1, 64-74,

Madeline Polmear

An overview on informal learning that includes theoretical perspectives and opportunities for future research:

- Polmear, M., Chance, S., Hadgraft, R., & Shaw, C. (2023). Informal learning: Opportunities for competency development and broadened engagement. In A. Johri (Ed.), *International Handbook of Engineering Education Research*.

Corrinne Shaw

- Malebogo N. Ngoepe, Kate le Roux, Corrinne Shaw, Brandon I. Collier-Reed, (2022). Conceptual Tools to Inform Course Design and Teaching for Ethical Engineering Engagement for Diverse Student Populations. *Science and Engineering Ethics 28*(2).

Jan van der Veen

There are many ways to do case studies. Whatever mixture of quantitative and qualitative research methods you use, make sure you present a rich story.

- MacLeod, M. and J. T. van der Veen (2020). Scaffolding interdisciplinary project-based learning: a case study. *European Journal of Engineering Education 45*(3): 363-377.

Esther Ventura-Medina

This is a short publication that I always keep at hand because it provides a good grounding on theory, classroom issues and research questions in the context of education frameworks that are commonly used in engineering education research:

- Svinicki, M. D. (2010). A guidebook on conceptual frameworks for research in engineering education. *Rigorous Research in Engineering Education, 7*(13), 1-53.

Bill Williams

This article focuses on the engineering workplace and how future engineers can create value:

- Trevelyan, J., & Williams, B. (2019). Value creation in the engineering enterprise: an educational perspective. *European Journal of Engineering Education, 44*(4), 461-483.

Chris Winberg

Many of the doctoral students are doing innovative work - exploring new concepts, new methodologies, and challenging assumptions. Here I tried to explore and apply new concepts, try out new (and not yet generally accepted) methods, while challenging assumptions about the kinds of learning that happens in laboratories - might inspire doctoral scholars in their own work.

- Winberg, C. (2021). The Making of Engineering Technicians: Ontological Formation in Laboratory Practice, *Engineering Studies, 13*:3, 226-248.

Karin Wolff

Enabling students to develop complex thinking & practices:

- Wolff, K., Kruger, K., Pott, R., & de Koker, N. (2022). The conceptual nuances of technology-supported learning in engineering. *European Journal of Engineering Education*, 1-20.

Alternatively, for the students working with technology in education:

- Wolff, K. & Booysen, M.J. (2019). The smart engineering curriculum. *Proceedings of the 8th Research in Engineering Education Symposium*. Cape Town.

In addition, Maartje van den Bogaard, Anne Gardner, John Mitchell, Johannes Strobel, and Roland Tormey shared their recommendations verbally.

2.2 Reading Recommendations from the Experienced Researchers

Next, the senior researchers were asked to give input following the prompt: *Recommend one paper, not your own, for a starting PhD student?* This resulted in a comprehensive collection of publications, with some notable overlaps.

Una Beagon

I went to Scott Daniel's SEFI presentation on this paper early in my PhD and came out of it thinking.... oh I'll do phenomenography - I get that.

- Daniel, S. (2022). A phenomenographic outcome space for ways of experiencing lecturing. *Higher Education Research and Development 41*(3).

Jonte Bernhard

- Case, J. M. (2019). A third approach beyond the false dichotomy between teacher- and student-centred approaches in the engineering classroom. *European Journal of Engineering Education, 44*(5), 644-649.

Tom Børsen

When I did my PhD in university education this chapter helped me navigate in the different paradigms of qualitative research:

- Lincoln, Y. S., Lynham, S. A., & Guba, E. G. (2011). Paradigmatic controversies, contradictions, and emerging confluences, revisited. *The Sage Handbook of Qualitative Research, 4*(2), 97-128.

Jenni Case

I am not sure there is one paper I would recommend to everyone. Start reading on the topics and puzzlements that you care about and see where that takes you. But if you want to think about the context in which we work:

- Lucena, J., Downey, G., Jesiek, B., & Elber, S. (2008). Competencies beyond countries: the re-organization of engineering education in the United States, Europe, and Latin America. *Journal of Engineering Education, 97*(4), 433-447.

Shannon Chance

This handbook provides a wide overview of research in our field and has an impressively diverse group of authors. It's a great introduction to the field, and a who's who of sorts:

- Johri, A. (Ed.). (2023). *International Handbook of Engineering Education Research*. Routledge.

Tinne De Laet

- Fleur, D.S., Bredeweg, B. & van den Bos, W. (2021). Metacognition: ideas and insights from neuro- and educational sciences. *npj Sci. Learn. 6*, 13.

Inês Direito

Engineering education researchers' social identities – their backgrounds, world views, experiences and biases – have an impact on their research. This paper is a call for reflexivity and discussion of the ethics of conducting research.

- Secules, S., McCall, C., Mejia, J.A., et al. (2021). Positionality practices and dimensions of impact on equity research: A collaborative inquiry and call to the community. *Journal of Engineering Education, 110*(1), 19–43.

Xiangyun Du

- Direito, I., Chance, S., & Malik, M. (2021). The study of grit in engineering education research: a systematic literature review. *European Journal of Engineering Education, 46*(2), 161-185.

Kristina Edström

Go through a few recent issues of different journals to understand the publication landscape and what is required from a manuscript. It’s a good activity for a journal club!

Cindy Finelli

- Borrego, M. (2007). Conceptual difficulties experienced by trained engineers learning educational research methods. *Journal of Engineering Education, 96*(2), 91-102.

David Knight

- Davis, M. S. (1971). That's interesting! Towards a phenomenology of sociology and a sociology of phenomenology. *Philosophy of the social sciences, 1*(2), 309-344.

Anette Kolmos

- Arthur, W. B. (2009). *The nature of technology: What it is and how it evolves*. Simon and Schuster.
- Barnett, R. (2000). Supercomplexity and the curriculum. *Studies in Higher Education, 25*(3), 255-265.

Greet Langie

- Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic literature reviews in engineering education and other developing interdisciplinary fields. *Journal of Engineering Education, 103*(1), 45-76.

Joyce Main

- Griffith, A. (2010). Persistence of women and minorities in STEM field majors: Is it the school that matters? *Economics of Education Review. 29*(6). pp. 911-922.

Diana Adela Martin

This paper by Direito, Chance and Malik, is a standard for conducting a systematic literature review. There are no better EER scholars to learn this process from.

- Direito, I., Chance, S. & Malik, M. (2021). The study of grit in engineering education research: a systematic literature review, *European Journal of Engineering Education, 46*(2), 161-185.

Abel Nyamapfene

One of the biggest challenges when moving from technical engineering research to engineering education research, is getting a grip on research methods. This paper, though it's now 12 years old, is a discussion of research methods that a budding EER researcher might want to know more about.

- Case, J.M. & Light, G. (2011). Emerging Research Methodologies in Engineering Education Research. *Journal of Engineering Education, 100*(1), 186-210.

Madeline Polmear

An introduction to qualitative methodologies:

- Case, J. M. & Light, G. (2011). Emerging research methodologies in engineering education research. *Journal of Engineering Education, 100*(1), 186-210.

I also recommend the *International Handbook of Engineering Education Research* (Johri, 2023) since it covers a range of topics and offers fundamental and state-of-the-art insight into the field.

Corrinne Shaw

It depends. Have a conversation with me and I will make a recommendation.

Jan van der Veen

Inspirational combination of theory and practice:

- Klaassen, R. G. (2018). Interdisciplinary education: a case study. *European Journal of Engineering Education, 43*(6): 842–859.

Esther Ventura-Medina

This article by Borrego and Douglas about methods covers quantitative, qualitative and mixed methods approaches:

- Borrego, M., Douglas, E. P., & Amelink, C. T. (2009). Quantitative, qualitative, and mixed research methods in engineering education. *Journal of Engineering Education, 98*(1), 53-66.

Bill Williams

Particularly useful for researchers coming from an engineering or natural sciences background:

- Case, J. M., & Light, G. (2011). Emerging research methodologies in engineering education research. *Journal of Engineering Education, 100*(1), 186-210.

Chris Winberg

This offers some insights on what we're all trying to do:

- Patrick, A. Y., Wisnioski, M. H., McNair, L., Ozkan, D. S., Reeping, D., Martin, T. L., ... & Haines, C. E. (2023). In it for the Long Haul: The Groundwork of Interdisciplinary Culture Change in Engineering Education Reform. *Engineering Stud*ies, 1-24.

Karin Wolff

For students looking at institutional/leadership/change strategies:

- Garraway, J., & Winberg, C. (2019). Reimagining futures of universities of technology. *Critical Studies in Teaching and Learning, 7*(2), 38-60.

2.3 Advice from Experienced Researchers

Seniors were also asked to give one general tip for a starting Ph.D. student.

Una Beagon

Use this SEFI to attend presentations on methodologies that you are thinking of (if you have not yet decided) rather than the topics of interest. I find that being confident about your methodology is the hardest part of the PhD.

Jonte Bernhard

Think through your research question(s), i.e. find interesting problems you want to investigate. In my opinion the quality of the insights generated is more important than mechanically following a method.

Tom Børsen

Remember, it is your project.

Jenni Case

READ!!!! THINK!!! TALK with others!!! Seriously – there are shortcuts you can take – but if you want an experience that is intellectually transformative (first prize) I think this is the only way forward.

Shannon Chance

Extend your network! Look for people you'd like to collaborate with in the future and cultivate mentors to give you advice and references in the future.

Tinne De Laet

Talk to your colleagues, also the ones of other domains. They well help enrich your work and broaden your horizon.

Inês Direito

Doing a PhD can feel very lonesome, things will not always go according to plan, and you may feel you are not making progress or getting enough feedback. Whatever it is, never struggle on your own! Talk to other colleagues, friends and family, supervisor(s), mentors(s), or mental health professionals. Don’t forget to have a life outside work and enjoy your PhD!

Xiangyun Du

Feel safe to be creative. A PhD project is a process to construct your own academic identity.

Kristina Edström

Become an active participant in the research community. For instance, become a reviewer – you learn a lot from reading and critiquing others’ work and seeing the review process from the other side.

Cindy Finelli

Remember that there is more to life than your dissertation – make it a priority to take care of yourself!

David Knight

Be curious.

Anette Kolmos

Focus - focus - and more focus. Work on the research questions.

Greet Langie

Stay passionately curious! Do not stop questioning. No one will ever blame you for this, on the contrary.

Joyce Main

Self-care is an important priority. Write a little every weekday.

Diana Adela Martin

The EER community is fantastic and grew via mutual support and friendships. Feel welcome to reach out to the researchers you admire, to ask for advice from a potential mentor, to discuss with the author their paper, to propose projects to SIG chairs or other group leaders of networks or associations in your area of research. And if you are interested engineering ethics education (broadly conceived), or have a suggestion for a project for the SEFI Ethics SIG, especially if it is something you would like to lead, reach out to me.

Abel Nyamapfene

The doctoral process is a marathon and not a 100 metre sprint. Be gentle to yourself, take your time, there is a lot to take in, don't panic, we have all been there.

Madeline Polmear

Have a constellation of mentors. Instead of relying only on your PhD supervisor for information and advice, seek out different mentors who can support you for various purposes, such as career development and personal growth.

Corrinne Shaw

Make sense of your ideas, puzzling through, thoughts and work by writing. Write, write and write some more. Write first for yourself, for sensemaking before you refine or translate for anyone else.

Jan van der Veen

Enjoy the journey and connect with fellow travellers.

Esther Ventura-Medina

Think carefully what question you are asking and try to fit your theoretical lens and methods to this.

Bill Williams

The field is large. Find particular researchers whose work really speaks to you. Then find a way to speak to them.

Chris Winberg

The PhD is lonely journey - so connect with a supportive group - or groups – for example a reading group (I am part of a reading group that includes doctoral scholars and supervisors who are using Activity Theory) and a writing group, such one that meets once a week to either 'just write' and sometimes to talk about writing can make the journey more collegial.

Karin Wolff

Be organised, have a dedicated space and allocated time slots for uninterrupted work. With good systems in place (including document management), it is also important to have peer/mentor/family support structures. The PhD journey can be overwhelming and lonely, but by recognising the importance of 'systemic' and 'affective' support, the ultimate goal of 'cognitive' development and contribution can be achieved.

2.4 Group Notes

The groups wrote collaborative notes during their time together and then prepared notes using an online file. These were valuable, yet lengthier than could be included here.

2.5 Take-Home Messages

As the final activity in the day, the organisers invited each participant to share one nugget of wisdom gained, as a take-home message from the DS. This final plenary provided each attendee with one minute to present a take-home message. The messages from doctoral students and seniors appear below:

Zeyi Liu, Michael O'Connell, and Nicola Rice: We got a lot of information about possible future research domains. WhatsApp and the networking opportunities during the conference will be used to continue discussions. The flow of knowledge is amazing. Thanks to this strong network, I will be able to save a lot of time. I gained a lot of new knowledge. I will pay attention to learning to synthesize and synopsize. It's important to learn to explain your research to a non-academic audience. The variety of projects is impressive. The PhD's have ownership of their research! We are all sponges of knowledge.

Maiken Winther: Context of the PhD is very important to understand the results: educational context (What does it mean to be admitted to this university? What is it like to study here? What does life look like after graduation for these students?)

Lisa Hagedorn: Focus is very important: you don't need to do everything → pick a slice that you want to focus on.

Shan Tuyaerts: Experienced and foreseen challenges are also important research outcomes, as well as potential future research directions.

Esther Ventura Medina: Good research leads to more questions than answers. Your research will not go the way you expected it to. It is more important to answer a meaningful question and provide new insight rather the original question.

Saul Garcia Huertes: Take just one issue and stick to it.

Jenni Case: Contributions from the PhD might be different: to theory, to practice or to methodology but it is important to have a good story.

Shameela Arbi: Scope and methods can always change throughout the PhD process, but it's important to love your topic or area of research. It is not easy to dedicate years of your life to something you're not passionate about.

Yiduo Wang: It is okay to be flexible and make compromises if the previous plan seems too challengeable. The end of the PhD is not the end of life, instead, is the start of the academic career.

Eugenio Bravo: Plan your work and work your plan to get your PhD done.

Eva Murphy: Allow for things to not go as planned.

Sandra Cruz Moreno: My main takeaway is to narrow down my research topic, and to focus on (re)formulating my research question and make it answerable. The second is to network with the EER community while enjoying the process. Lot of fellow researchers agreed that this community is very welcoming and supportive.

Julia Sundman: It is interesting to see the diversity of backgrounds that EE researchers come from – it is also comforting that although not everyone has a background in engineering or educational sciences, we are all motivated by the desire to advance engineering education to respond to the society's and planet's needs. The need to facilitate boundary-crossing in engineering education is clear, and this should be understood further not only in learning contents, students' interactions, but also in collaborative teaching practices among teachers.

Ann-Kristin Winkens: Exchange is everything, especially when starting the PhD, because most of us are newcomers in a cross-/interdisciplinary research field. Engineering Education Research is boundary-crossing, so we need to be open and curious for other perspectives and ways of thinking.

Anette Kolmos: It is such a pleasure to see the growth of the community and the hope for development and innovation of engineering education. I also hear that sustainability, interdisciplinarity, humility, collaboration, challenge- problem- project based learning maybe has become a mainstream element in engineering education. Thanks to the organisers and thanks to the group members.

Jan van der Veen: I see a worldwide community now, great. Topics shared widely are the ways sustainability is included in education but also how engineering education can become more inclusive. Many have a background in science or engineering themselves, a great asset but also an extra challenge to familiarize oneself with social science methods.

Kate Bellingham: There are many different ways of doing this journey - enjoy your voyage of discovery.

Dione Maluwa: It is okay to feel inadequate on this PhD journey because you are embarking on something that very few people will, so be kind to yourself.

Beyza Nur Guler: Your research questions might change along the process. It is important to narrow down your research topic and devote your career to the rest. Curriculum design has stages design, implementation and experiences of students.

Johannes Schleiss: Three learnings: (1) Learning from topics and different perspectives helps, even though the topics are not connected in the first place. (2) Support networks are key and helpful. (3) Measuring impact of change is challenging.

Xiangyun Du and Maartje van den Bogaard: Many of you are doing PhDs outside of your own field of training. That is pretty bold! When in trouble or doubt: keep on moving forward! Be bold and pragmatic in taking steps towards operationalization, choosing your theoretical framework, etc. It doesn't have to be perfect: it needs to be informed.

Tom Børsen: There are trends and great possibilities for synergies between many projects. Many research transformative learning, diversity, sustainability, longitudinal studies, interdisciplinary challenges.

Eugene Leo Draine Mahmoud: Clarify and narrow the research questions and their expected impact, use purposeful sampling within qualitative methods, focus student narratives on assets and successes, incorporate intersectional student identity, ask for help.

Luke Dokter, Erna Engelbrecht, Tina Anne Fuhrmann, Callum Kimpton, Una Beagon, and Roland Tormey: Come to SEFI every year to recharge your research batteries. Write one PhD (not three). Be clear about how you have been systematic in data collection and analysis so as to clearly address your research question.

We need to allocate time to sufficiently reflect over the experiences/impressions from the day, but how ar ewe to do this when we are about to embark on a 4-day conference?

Rani Dujardin, Pleun Hermsen, Olga Ovtšarenko, Ina Peters, Cindy Finelli, Abel Nyamapfene, and Corinne Shaw: Claim credit for what you do! Speak of yourself as a singular person, not as the speaker of a whole research group. Narrow down your PhD topic. The thesis is the beginning of something, not the end. These conversations helped clarify next steps. We need reflection time to think about everything we heard, everyone for themselves. Broad access to publications is a hot topic.

In other words, many universities cannot pay open access fees, others cannot afford licenses for closed access publications. We need to find ways of sharing knowledge within the community. Interesting ideas to pursue as next steps forwards.

Alba de Agustin Camacho: I have learnt about options for journals and conferences. I have enlarged my network. I got interesting input to keep working on my PhD.

Bill Williams: Find your community.

Anna Overgaard Markman: My main take-home message is the importance of community. I have my research group in Aalborg, but it's interesting to meet researchers within the field from different parts of the world.

Fatima Darsot: My main take-home message is that you need a "village to work on your research" and to build it.

Johannes Strobel: Any research can be improved from coming from a different perspective, things can duplicated in so many different traditions.

John Mitchell: There are always interconnections between research, despite what first impressions might be and therefore all experience sharing is valuable.

Svend Christiansen, Camilla Bjorn, Hanna Aarnio, and Tasha Zephirin: Be a rebel with support… [apropos Be a rebel with a cause!!!]. It's helpful to continuously talk about your topic to different audiences to clarify what you're doing [new insights and energy]. Visualize your topic/research interests and be strategic about your yes/no/not yet! You can continue developing your theoretical framework also after completing your PhD thesis.

Shannon Chance: Understand that this is a very welcoming community and feel free to reach out to anyone in this room today with questions or ideas for projects – even those who seem like superstars in the field are likely to respond and help you. I know this first-hand!

Jonte Bernhard: I am glad that so many could participate in the symposium today. I hope the symposium has inspired you and you have learned something. As we hope you have experienced today you will always learn something by extending your network and you get new perspectives from visiting other institutes and communicating with people outside your own close circle. Never stop to keep your mind open!

3 REFLECTIONS AND WAY AHEAD

The 7th DS was the most well-attended, dynamic and interactive SEFI Doctoral Symposium so far. The growing number of participants is an indicator of the strong reputation of the DS over the years, but also of the growing maturity of the research field on engineering education. It is delightful to see a healthy and growing community of researchers across and beyond Europe. With 37 Ph.D. researchers and 27 established scholars giving their all to the community, and to uplifting each other, the field of EER seems to have a bright future.

It is impressive that so many leading experts in the field are willing to donate significant time and effort to mentor others and to help make SEFI a world-leading community for presenting research, collaborating, and sharing ideas. However, it is certainly not only the Ph.D. researchers who benefit and learn in the doctoral symposium; the senior mentors and organisers benefit as well. Senior participants reported that they felt honoured to share their thoughts and ideas with the junior researchers. They appreciated networking with juniors and seniors alike and having the chance to "spot new talent". As reported in a blog by Chance (2023), "*It was, in all honesty, a highlight of the overall week, and each participant shared insights at the end of the day. 'I found my village' exclaimed one of the PhD students to resounding applause. Indeed, this annual symposium, where experienced researchers provide one-to-one advice to doctoral students helps bring our research community together.*"

As recent years have brought larger and increasingly enthusiastic participation to this Doctoral Symposium, with dozens of junior and senior participants joining, significant participation from outside Europe can also be noted. Their diverse presence makes valuable contributions to the dynamic discussions and enables the development of global connections within the field.
The authors are delighted with the expanded capacity of our community to conduct research with strong scholarly grounding and usefulness to readers. We are dedicated to helping foster individuals and the unique abilities, insights and perspectives each new member brings to our community. We observe new and thriving publication venues, and value the vibrant sense of community that characterised this year's doctoral symposium. We hope to stay connected with this year's participants and see all of them again at coming SEFI conferences.

4 ACKNOWLEDGMENTS

The authors wish to thank every participant in the DS since its inception in 2016. The success of the activity is a direct result of the engagement and enthusiasm of juniors and seniors alike. We also thank the local and international organizing committees over the years, including Ger Reilley for his outstanding support in 2023. We thank the SEFI staff and board for entrusting us with the facilities and resources to help make this event possible.

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Research Papers

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SUSTAINABILITY IN ENGINEERING AND ENGINEERING EDUCATION: A COMPARATIVE STUDY OF GERMAN AND SAUDI ARABIAN INDUSTRIES

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ABSTRACT

Sustainability has become a major concern in the fields of engineering and engineering education. Organizations such as UNESCO have defined goals for sustainable development in engineering. As engineers design, develop, and implement products and processes that impact the environment and society, their role in promoting sustainable development is vital. Addressing sustainability in engineering curriculum is needed to equip engineers with the knowledge, skills, and attitudes required to develop sustainable solutions in their respective areas, and it involves merging the teaching of technical skills with a systems-based approach that considers the broader environmental and economical context of engineering. This

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requires collaboration between different disciplines and stakeholders, including engineers, educators, policymakers, and industry.

This study investigates the industry practices regarding sustainability goals and measures in two countries. Another point of inquiry is to find practical recommendations from engineers and project managers to inform engineering education curriculum in terms of knowledge and awareness of sustainability. Qualitative case study protocol was followed in this research, and participants from Germany and Saudi Arabia were interviewed online. Thematic coding was performed to extract meaning making descriptions from the interview transcripts.

In response to the interview prompts, the participants shared their perspectives of sustainability in their area of engineering. Their recommendations towards the curriculum development included making UN sustainability goals a part of engineering curriculum, while still teaching students to adopt a ‘lean product development approach’ in their course projects, so that they learn the practical implementation of sustainability in engineering projects as well as in life.

1 INTRODUCTION

1.1 Background and Literature Review

The need for sustainable development is a very immediate one, defined and explained initially by the World Commission on Environment and Development (WCED) (WCED 1987) as utilizing the planet's current resources in such a way that future generations may also be able to benefit from them. In that sense, sustainability is an important issue to be addressed in engineering education (Glavič 2006).

Regarding engineering, sustainability has many dimensions, including environmental considerations for ensuring a safe and secure future for generations to come, countering global warming and reducing carbon footprint (Matthews, Hendrickson, and Weber 2008) to name a few. Globally, industries are investing a lot in how to make their material products sustainable. The emphasis is on increasing the quality of products to make them long lasting and durable, using biodegradable materials to manufacture equipment, finding renewable energy sources to run factories and workspaces, and reducing carbon footprint, chemical waste and plastic waste (Evode et al. 2021).

The world is facing a plethora of environmental, social, and economic challenges, such as climate change, resource depletion, and chemical waste which are intricately interconnected and can potentially lead to an uncertain future in terms of habitability of the planet. Governments, trade markets, companies, and engineers working in various disciplines have the responsibility to address these challenges in their respective capacities (Wilkinson, Hill, and Gollan 2001) and create solutions that promote sustainable development. Achieving sustainability requires a holistic approach that considers the entire life cycle of a product or system from raw material extraction to its recycling or disposal (Jawahir et al. 2006).

There is a growing body of academic research that highlights the importance of sustainability in engineering. For example, a study explored the integration of sustainability principles called life cycle sustainability assessment (LCSA) into the design process and building information modeling (BIM) process of buildings (Llatas, Soust-Verdaguer, and Passer 2020) in an attempt to achieve significant reductions in energy use, water consumption, and greenhouse gas emissions from the buildings. This research demonstrates that sustainable engineering practices can have a positive impact on the environment and help mitigate the effects of climate change. In addition to the benefits of sustainability in engineering, there is also a growing need for sustainability in engineering education. A study by Ramirez emphasized the importance of integrating sustainability principles into industrial design curriculum (Ramirez Jr 2007). The author argued that sustainability should be a core part of engineering education to teach students about the ecological impacts of their designs and how to minimize these impacts (Ramirez Jr 2007).

Another study explored the impact of sustainability education on the attitudes and behaviors of engineering students towards sustainability (Tang 2018). The authors found that students who received sustainability education had a greater understanding of the importance of sustainability and were more likely to consider sustainability in their future engineering projects as a moral obligation (Tang 2018). This research highlights the positive impact that sustainability education can have on students and their future engineering careers.

There are several challenges to integrating sustainability into engineering education, including the lack of resources, time constraints, and resistance to

change (Markvart 2009). However, there are also opportunities, such as strategies proposed for integrating sustainability into engineering education, including curriculum redesign towards sustainable development goals by United Nations Educational, Scientific, and Cultural Organization (UNESCO) (UNESCO 2005), project-based learning, and interdisciplinary collaborations (Guerra 2017).
In conclusion, sustainability in engineering and engineering education is a critical issue that cannot be ignored.

The researchers intend to address sustainability through a curricular approach by interviewing experienced engineers in Germany and Saudi Arabia, which as countries are far apart in terms of geographical locations, education systems, and industries. Germany is advancing towards automated industry through the industry 4.0 project (Lasi et al. 2014). On the contrary, Saudi Arabia holds an oil-based economy (Abuhjeeleh 2019). It would be interesting to see how engineers working in both the countries describe their companies' efforts towards sustainability. The goal is to learn about their perspectives regarding the importance of sustainability in engineering and their suggestions towards curricular reforms for better awareness of young individuals in undergraduate engineering programs.

1.2 Theoretical Framework

The research questions in this study are informed by the 'Education for Sustainable Development' (ESD) framework. ESD is defined as "a process of learning how to make decisions that consider the long-term future of the economy, ecology, and equity of all communities" (UNESCO 2005). The ESD framework provides a holistic approach to education that integrates social, environmental, and economic perspectives. It emphasizes the development of knowledge and awareness for students that enable them to participate in sustainable development.

Several studies have applied the ESD framework to engineering education, highlighting the importance of integrating sustainability into engineering curricula. For instance, Bergholm (Hofman-Bergholm 2018) recommended the interlinking of ESD with systems thinking approach to inform the practical implementation of sustainability in education. Comparably, in their implications for curriculum change, Kagawa (Kagawa 2007) reported that students associate the concept of sustainability to be against economic and social aspects, and therefore proposed an engineering curriculum overhaul to overcome such barriers in an attempt to let students realize their preferred futures (Kagawa 2007).

Overall, the ESD framework realizes the challenges of inculcating a sustainability mindset in students through engineering curriculum and provides practical solutions to achieve that goal.
This study aims to realize the full-time engineers' and project managers' knowledge and awareness about the issues pertaining to sustainability and looks at how the industry is implementing sustainability goals. Following are the research questions:
RQ1: How do experienced engineers and project managers perceive the issues relating to sustainability?
RQ2: How does sustainability relate to engineering education and how can sustainability be integrated into the engineering curriculum?
These research questions attempt to explore the concept of sustainability in industry of two countries and bring the industry best practices to inform engineering curriculum in academia.

2 METHODOLOGY

2.1 Study Design

This research is designed as a comparative case study, in which a ‘case’ represents a choice of what is to be studied (Creswell and Poth 2016). Furthermore, this study is not chronological in nature and is based on examining particular scenarios bounded by a limited timeframe (Creswell and Poth 2016). Approaching the issue of sustainability through a case study approach makes sense for this research in a way that researchers want to investigate how the issue is addressed in industry and academia at different geographical locations. Through this study, the researchers aim to shine light on the importance of including the teaching and awareness of sustainability-related concerns in the curriculum of all areas of engineering.

2.2 Sample

Sampling for this study constituted experienced engineers and project managers who worked in Germany and Saudi Arabia. The sample size was 8, including 4 participants from Germany and 4 from Saudi Arabia. Recruitment was done by forwarding recruitment emails to academic and professional connections as well as through snowball sampling, meaning that the recruited participants were requested to find further participants from their professional connections and circles. Certain criteria were set to make sure that participants were aware of the current industry best practices around sustainability. In order to be eligible to participate in the study, following criteria were to be met by the individuals:

Engineers: Engineers were required to have graduated within the past five years from their university in Germany or Saudi Arabia, and to have full-time industrial experience of at least 4 years.

Project Managers: Project managers were required to have full-time industrial experience of at least 15 years and to have served in a corporate-level management position for a minimum of 5 years.

2.3 Instrument and Protocol

The protocol followed in this case study was semi-structured interviews. Participants were contacted remotely via Zoom and their audio and transcriptions were recorded. Interviews started with a brief introduction of the researcher and participant in terms of area of research and industrial experience, followed by open-ended prompts regarding sustainability definitions and practices in their respective companies. Participants were also asked for their recommendations towards improving the engineering education curriculum to cater to the awareness of sustainability among engineering students. Care was taken to maintain the anonymity of participants by assigning pseudonyms to them and their companies.

2.4 Analytical Method

This case study implemented a thematic coding approach to analyze interview data collected from participant audio transcriptions. The analysis involved assigning codes and subcodes to specific groups of information in the transcripts, followed by a holistic determination of repetitive and similar codes appearing in multiple participant transcripts. The information relevant to those codes was then regarded as ‘emergent’ which led to ‘themes’ from the data that answered or tended to answer the research questions for this study. Those emergent themes were used to report the findings as well as inform the discussions section of this article. As a whole, only the participant perspectives have been reported in the findings section, while researchers’ perspectives have been discussed in the later sections.

3 RESULTS

As this is a comparative study, findings have been divided into two groups based on the geographical location of participants. Initial codes indicated that participants defined sustainability in varied ways depending on their area of engineering. However, several participants had similar experiences regarding their companies’ efforts towards sustainability goals.

3.1 Participants from Germany

A participant is a senior mechatronics engineer with a master’s degree working in the German automotive industry for the last five years. His daily work involves autonomous driving systems and advanced driver assistance systems such as adaptive cruise control and lane assist. The participant believes that sustainability is a hot topic in the value chain and that the life cycle sustainability of products such as electric vehicles (EVs) and active hybrid cars should mainly involve minimizing the overall carbon dioxide emissions. Even for the traditional combustion engine technology, the automotive companies are finding ways to reduce emissions. In terms of the European laws about sustainability, a participant explained that Germany plans to discontinue diesel engine production by 2030 and petrol engine production by 2035. Simultaneously, companies are investing in improving fuel cell technology and also making it more affordable. In that regard, Toyota has built a prototype fuel cell powered car whereas Mercedes is developing a fuel cell powered bus. Similarly, Mercedes has replaced original leather seat covers in cars with synthetic alternatives and traditional plastic parts in cars with recyclable alternative plastics in an effort towards a more sustainable system. Although that participant’s current role in the company is not a corporate-level decision making role, he still believes that ample background knowledge and awareness about sustainability is very important for every engineer and should be addressed properly in the university curriculum. He recommends that engineering students should be thought to adopt a ‘lean product development approach’ in their course projects with focus on minimizing expenses and maximizing market value and profits, but at the same time care about the durability and sustainability of the product as important concerns.

Another participant with three years of experience in avionics-related software exclaimed that he was not taught about sustainability in his undergraduate and master level courses. However, his current company is working on a data transfer simulation module for Field Programmable Gate Array FPGA chips and mostly deals with software and coding aspects. In his area of engineering, sustainability efforts involve reducing and optimizing code to use minimum memory resources on microchips. This helps in conserving the natural resources utilized to make microchips which is an important aspect of sustainability towards saving natural resources for future generations.

3.2 Participants from Saudi Arabia

Most of the participants from Saudi Arabia worked at some of the biggest oil companies in the world, in part since crude oil and petroleum products are the biggest exports of the region. A project manager with over 25 years of experience at Saudi's 2nd largest construction company, linked sustainability in his company with the UN sustainability goals defined in 2004, saying that sustainability became the cornerstone of all big engineering projects in the world after that. In another participant's view, engineers need to radically shift to a sustainable mindset in all areas including plastics, batteries, chemicals, and electronics. He warned about an issue that needs immediate attention on a global level, which is that permafrost is rapidly melting in the Arctic Circle due to global warming, and the process is releasing greenhouse gasses, especially methane gas which is 40 times more potent than carbon dioxide. While this is a big problem in the current scenario, the earth as a planet is on the verge of even bigger issues if the average global temperature increases by 1.5 degrees Celsius, such as runaway heating of the planet. In that case, methane hydrates found at the bottom floor of deep oceans and containing more than all the hydrocarbons that humans have been burning from the last 100 years, might rise to the surface, posing everlasting threats to the living ecosystems. The participant explained that recent developments in his company's sustainability policy have resulted into efforts towards decarbonizing operations, electrification, heat pump usage in terms of energy generation, addressing global warming by shifting methane-based steam cracker towards electrical based steam cracker, maintaining a circular economy with the plastic waste reduction and plastic recycling process, and improving resource and energy efficiencies.

In his recommendations toward improving the engineering education curriculum, a participant mentioned that the UN sustainable development goals should be a part of curriculum regardless of the area of engineering. The students must always think from a sustainability perspective, such as while designing and developing a product, think about where it will end up after its lifetime. The focus should be on earning carbon credits and reducing the carbon footprint on the planet by utilizing minimum resources from natural reserves and maximizing the efficiency as well as lifetime of the products. Mark also mentioned that the students need to be aware of the long-term sustainability concerns such as if the whole world moves to electrical energy generation through nuclear, it will only last 75 years; thus, we need renewable sources of energy such as solar, hydel, and wind.

Another participant, working in the drilling department of an oil company for 16 years, defined sustainability as a responsibility of our generation to secure the future of generations to come. His concerns regarding sustainability included minimizing environmental impact of material product wastes, reducing pollution and carbon footprint, carbon capturing, maximizing asset values, and circular economy. Sid emphasized that the issues regarding sustainability are so important that not only the engineering curriculum but also the elementary school curriculum should aware students and develop innate sustainability sense in them from childhood.

4 SUMMARY

4.1 Discussion

Regarding sustainability, the perspectives of engineers and managers working in Germany were quite different from those working in Saudi Arabia. This might be a consequence of different industry focus for the two countries. Germany has been working on an automated model of industry for a long time, (Lasi et al. 2014) minimizing the human input while maximizing the machine output, which is a step toward enhancing machine efficiency and life cycle and thus contributes to sustainability research. On the other hand, Saudi Arabia has remained an oil-based economy for a long time (Abuhjeeleh 2019) and only recently started investing in tourism, non-oil exports and renewable energy (Waheed, Sarwar, and Dignah 2020) which is apparent from the participant perspectives indicating a relatively recent shift towards sustainable economy, renewable energy, and other sustainability dimensions. Furthermore, the findings indicate that engineers in Germany are well aware of the sustainability challenges specific to their areas such as reducing the lines of code for microchips as a software sustainability concern and replacing automotive batteries and body materials with sustainable alternatives. In contrast, engineers and project managers in Saudi Arabia view sustainability in a more global sense, with less concerns relevant to their specific areas of engineering.

Nevertheless, knowledge and awareness about sustainability must be provided to engineering students throughout the course of their degree programs, and special attention should be given to the practical implementation of sustainability goals in their course projects.

Scholarly Implications: In authors' perspective, gaps do exist in the engineering curriculum of universities that can be informed of through more nuanced research in different areas of engineering, such as chemical, civil, electrical, material, computer science, software, and so on. Sustainability in engineering is a broad area and the relevant perspectives of engineers can be explored more by subdividing it into categories such as robotics, automotive industry, automation, aircraft industry, petroleum industry, and so on. It is expected that the implementation of sustainability goals would be very strict in the automotive and airplane manufacturing industries as compared to a software company per se, as a consequence of fuel consumption of cars and airplanes linked directly to the global carbon footprint and pollution. That might provide interesting perspectives about how important sustainability goals are to a particular industry.

Practical Implications: This study hopes to inform practical changes in the engineering curriculum pertaining to sustainability concerns. The findings from engineers clearly indicate a need to immediately address the lack of awareness about sustainability goals in engineering programs. On a larger scale, this study may be utilized to render educational policy makers more aware of the issues regarding sustainability in academia.

4.2 Limitations and Future Directions

This is a qualitative study and the sample size is appropriate, still more participants might affect the findings and conclusions of this study. Moreover, only male participants were inducted in this study. The reason for that is not the researchers' bias toward a specific gender; rather the sampling strategy used which was snowball sampling resulted in male participants referring their same-gender industrial connections and collegues. Thirdly, the issue of sustainability is worldwide, whereas this case study investigates the industry in two countries only. Not purposefully so, but that depicts only one piece in the complex puzzle, and thus the results of this study are not generalizable to all scenarios regarding sustainability. These limitations, however, could be addressed in future studies to include a more inclusive sample and hopefully inform more practical approaches to engineering curricular reforms in terms of sustainability.

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DISRUPTIONS TO THE "MODELED MINORITY" IN ENGINEERING: WHY DO SOME ASIAN AMERICAN STUDENTS LEAVE ENGINEERING?

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ABSTRACT

Asian American students are the largest non-White racial group in US undergraduate engineering, but they are often labeled as the "model minority." This stereotype confines them to STEM majors, limiting their access to diversity, equity, and inclusion (DEI) programs. Little attention has been given to why some Asian American students leave engineering. To address this gap, a pilot study using semi-structured interviews aims to explore the reasons behind their decision to leave the field or change their major. The study seeks to contribute to engineering education scholarship by promoting more inclusive learning environments for Asian American students and providing recommendations for better support from faculty, administrators, and staff.

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1 INTRODUCTION

Asian American students are the largest non-White racial group in US undergraduate engineering, though they are still considered members of a unique minority population - the "model minority." However, scholars in Asian American studies

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continue to disrupt the norms placed on Asian American students. And with the stereotypes of Asians as geeks and doctors, Asian American students are typically boxed into STEM-oriented majors, thus further forcing Asian American students to take on the “modeled minority” stereotype. Here, we use the term “modeled minority” as this stereotype is perpetuated by STEM. Unfortunately, traditional approaches to framing and justifying research concerning minority students based on concepts such as representation and retention might be challenged when examining the experiences of Asian American students in engineering. Even if we are able to solve the problem of representation, we argue that it may not completely remove racial inequity against Asian American students from engineering education (Trytten et al. 2009). Despite being “overrepresented,” Asian American students in engineering (and Asian American students in general) in the United States are still facing racial discriminations, stereotypes, microaggressions, and other forms of systematic anti-Asian racism. To a large extent, the model minority myth and the overrepresentation concern challenging Asian American engineering students has limited their access to DEI programs.

Traditional DEI-focused studies in engineering education often focus on how to retain minority students especially those from Hispanic and African American backgrounds in engineering. Arguably, excluding Asian American students from retention research in engineering might assume either: (1) there is no retention issue among Asian American engineering students (again derived from the overrepresentation assumption); or (2) the traditional retention framing is not effective in serving the DEI needs of Asian American students.

Nevertheless, contrary to stereotypes around the model minority, our anecdotal evidence suggests that Asian American students (at least some of them) *do leave engineering*. Given the two assumptions articulated in the last paragraph, these students are not usually or necessarily included in most DEI programs, despite that a major goal of these programs is to retain minority students in engineering. We argue that one overlooked and yet critical aspect of DEI research in engineering is why some Asian American students leave engineering. While there have been limited studies in both engineering education and the social sciences regarding Asian American student experiences in engineering, even less attention has been brought to why some Asian American students leave engineering.

This pilot study aims to explore the paths some Asian American students took in deciding to leave either the field of engineering or engineering as a major. Semi-structured interviews are utilized to capture and center students’ experiences as first-hand accounts as to why these students leave engineering. This paper concludes with recommendations for engineering education and faculty, administrators, and staff for better supporting Asian American students during their journeys in engineering. This paper will contribute to the scholarship in engineering education that explores the diverse experiences of Asian American students in US engineering and more authentic approaches to the creation of inclusive learning environments for students from all backgrounds.

2 LITERATURE REVIEW

2.1 Asian American Students in Engineering Education

Based on previous scoping reviews, there has been a significant scarcity of empirical research regarding the experiences of Asian American students in US engineering education, both within the engineering literature and the social sciences literature. In the scoping review of the engineering literature, only three papers that empirically investigated Asian American students in engineering or STEM programs. A similar scoping review of the social sciences literature found only 14 papers, of which two were included in the previously mentioned literature review. Of the existing literature about Asian American engineering students in the US, there are two major areas of focus: (1) how Asian American students enter the STEM pipeline; and (2) the lived experiences of Asian American students during their time in engineering education.

The first area focuses on how Asian American students enter the STEM pipeline. One quantitative study found that individualistic student choice rather than parental influence were strong predictors for Asian American students to choose STEM over liberal arts and business majors (Lowinger and Song 2017). Lowinger and Song (2017) defined parental influenced variables such as parental education, parents' savings, parenting style, and level of involvement in their children's schooling while student variables included advanced placement and college preparation programs, subject preparation, extracurricular activity engagement, and student test scores. Another quantitative study examined the pathways to STEM majors for Asian American students and found that entrance to STEM varied among different Asian American ethnic subgroups, thus disrupting the model minority myth (MMM) (Kang et al. 2021). For instance, Filipino students were less likely to choose STEM majors compared to other Asian subgroups of students and Indian/Sri Lankan student choose STEM majors more than any other subgroup. Pang (2023) focused on how Asian American female college students, mostly STEM majors, decided to choose their major and the factors that influenced their agency in deciding their major such as family influence, personal expectations, and gendered expectations.

The second area centers on the lived experiences of Asian American engineering students in the US, throughout their time in engineering education. One quantitative study, centered on Asian American engineering students in the University of California system, found variations between classroom engagement and GPA across different sub-ethnic groups (Ing and Victorino 2016). One mixed-methods study focused on Asian American engineering students found that these students continued to experience racist stereotypes but also projected these stereotypes onto other Asian American students (Trytten, Lowe, and Walden 2012). Another study focused on examining the stereotypes Asian American students endure during college found that students indicated the stereotypes of the MMM and expectations to excel in math and science devalued the work they did to get where they were (Museus and Park 2015). In a phenomenological study, researchers looked at how Asian students navigated the social and psychological impacts of the MMM in their STEM education which backed up claims in disrupting the MMM (McGee et al.

2017). One paper summarizes the (lack of) literature and research on APIDA and Southeast Asian and Pacific Islander American (SEAPIA) students in STEM, specifically focusing on the importance of students' interactions with faculty which feed into factors of retention and persistence (Eleno-Orama and Ross 2019).

2.2 Minority Students Leaving Engineering

Historically, a major concern for engineering education research is how to sustain the engineering workforce pipeline. Researchers and policymakers in engineering education have explored ways to retain students, especially those from underserved cultural backgrounds in the engineering profession. To better study how to retain minority students in engineering, some scholars have studied the factors that may potentially cause them to *leave engineering*.

Hughes (2018) found that factors such as participation in undergraduate research, STEM identity, having a parent employed in STEM, and high school GPAs and SAT scores can potentially predict the retention of sexual minority STEM students. Watson and Froyd (2013) discuss how the leaky pipeline diagram, popularized to showcase how students leave STEM, indicates that engineering systems are geared to "plug" rather than renew the culture of engineering. Park et al. (2020) found that Black and Latina women were more likely to leave STEM due to racial and ethnic discrimination from their STEM professors. Hall et al. (2015) determined that strong predictors for retention in engineering included high school GPA, SAT math scores, and Assessment and LEarning in Knowledge Spaces (ALEKS, a placement test measuring calculus readiness).

In summary, the existing literature in engineering education has yet problematized the experiences of Asian American students. More specifically, the literature on minority students leaving engineering has not considered Asian American students. Therefore, the major research question for this exploratory study is: ***What are the factors that may potentially lead some Asian American students to leave engineering?***

3 METHODS

3.1 Study Setting and Participants

For this pilot study, qualitative methods were utilized to understand the narratives and experiences of the students. This study was approved by the University's Institutional Review Board for human subjects research (IRB approval number 23-461). Student participants were from a public Asian American, Native American, and Pacific Islander-serving institution (AANAPISI) located in the Southern region of the United States. This institution was chosen because as it holds AANAPISI status, indicating that at least 10% of the total undergraduate student population is of APIDA descent. In order to be considered for the study, students had to have started in the College of Engineering and transferred out of engineering prior to their undergraduate graduation.

If the student agreed to participate, a one-on-one semi-structured interview was conducted virtually, lasting 30 to 45 minutes. Semi-structured interviews allow for the student to share their lived experiences through open-ended responses to closed questions. The lead author conducted and audio-recorded the interviews, which were then transcribed. In the first stage of data cleaning, all personal information was de-identified. With the de-identified transcripts, the researchers on this project coded the interviews according to themes that organically emerged from the student interviews.

Rigor and trustworthiness were considered for this qualitative research study (Lincoln and Guba 1985). Credibility emerged throughout the pilot study from the positionality of the researchers, the iterative nature of the interview questions, and frequent debriefing sessions between the researchers regarding the interview transcripts.

3.2 Positionality Statements

The first author is a biracial Asian and white woman graduate student whose research focuses on Asian American and multiracial engineering students. The second author is an Asian man from China who was educated in both China and the United States. His research focuses on global engineering, engineering ethics, and ethics of AI and robotics.

4 RESULTS

For this pilot study, two students were interviewed about their experiences in engineering. Their backgrounds are shared in the table below (Table 4.0). It is worth highlighting here that this paper is an exploratory study and it does not aim to draw any systematic findings across the sample. It is unlikely that insights from the two interviews will reach any kind of saturation for any typical qualitative study.

NOTE: Our major goal of this paper is two-folded. On the one hand, since there is no existing work on Asian American students leaving engineering, we are eager to get some very preliminary sense about the experience of these “less typical” students. On the other hand, analysis of the two interviews will help us further refine our interview protocol and develop a more comprehensive code book as we are interviewing more participants.

Table 4.0 Demographic Information of Student Interviewees

Interviewee Psydonym	Year	Starting Major	Graduating Major	Ethnicity	First Generation
Sarah	Junior (Third)	Architecture → Computer Science	Cybersecurity (Business)	Chinese	Yes
Rebecca	Senior (Fifth)	Computer Engineering	Food Sciences	Filipina	No

4.1 The Lack of Care and Sympathy in the Classroom

Both Sarah and Rebecca shared that a major reason causing them to leave engineering was the lack of care, empathy, and teaching effectiveness among some engineering faculty in the classroom, especially those who were teaching mathematics subjects. They indicated that their mathematics courses were the tipping point for them in engineering. To a large extent, the lack of care and empathy in the everyday teaching of these faculty further help to reinforce some problematic and yet dominant engineering ideologies such as meritocracy.

For instance, Sarah's introductory calculus instructor made no attempt to connect with students which included not responding to students' emails. Even when Sarah had a question, her professor had no interest in helping her and instead the ways the professor spoke made students feel that they were stupid. Rebecca's multivariable calculus course left a similar bad taste. Rebecca recalled a moment when her professor made the course inhabitable: "my teacher literally was like, 'hey, you failed this test,' in front of the entire class." It is worth noting that both professors were international faculty and both Sarah and Rebecca considered that the cultural backgrounds may have contributed to some culturally insensitive practices in the classroom such as humiliating Sarah and other students, not being sensitive to diverse learning habits among students, and sharing aloud Rebecca's grade.

4.2 The Competitive Culture: Engineering as a Rat Race

According to Rebecca, a major cultural dimension of engineering that disengaged her from further pursuing her learning in engineering is the *competition culture* of engineering. Rebecca called the competition aspect of engineering a "rat race." Despite that she enjoyed the problem-solving spirit of engineering, she felt concerned about the overly competitive process of becoming an engineer. As noticed by Rebecca,

> I feel like it's [STEM] almost oversaturated, and it's just so competitive. It's kind of like a rate race right now. There are just so many people in engineering who want to do the same things, and they're all usually great people. But the issue is, in the end, they're all kind of your competition, which just sucks, because a lot of times it doesn't help when you want to build relationships with those people.

As indicated in the quotation above, in fact, the competition culture can be further worsened by the lack of diverse ideas in engineering. In addition, there can be consequences resulting from the competition culture. For instance, competition will make engineers unable to build relationships with their colleagues. In general, Rebecca's impression with the competitive culture in engineering is that it is so difficult to "break through." Rebecca later found the food science program she transferred to included more diverse topics and ideas.

4.3 Engineering Is Not for Everyone

Both Sarah and Rebecca shared their experiences interacting with their peers, advisors, and family members when they were considering leaving engineering for other majors. These different stakeholders in engineering students' ecological system all indicated that it is totally fine to leave engineering simply because *engineering is not for everyone*.

When Sarah consulted with a friend in her calculus class that she planned to leave engineering, her friend was trying to comfort and said, "yeah, I get it. It's like some majors are not for everyone, and it's okay." More broadly, Sarah reflected on her experience discussing the relationship between gender and engineering and realized that engineering is still a male dominant field. As Sarah pointed out,

> But I do feel like there is still very much a male dominant field and they're kind of like, the males, they still kind of have that superiority complex, be like, "oh yeah, a woman can't do the field thing." Because I've heard from other friends, some of the guys do that because they're like, "Oh, I'm going to take over this whole project. You don't have to do anything."

Rebecca's experience with that engineering is not for everyone came from a more institutional approach. When discussing her experience with the process of switching majors, she cited the university's involvement:

> He [academic advisor] was a transitional advisor, specifically an advisor for people who are changing out of majors…I didn't know [they had transitional advisors] either until I got an email saying, "Hey, you're not doing great in engineering" and I was like, "Okay."

Thus, Rebecca was flagged by the College of Engineering on low performance, which led to the process of her leaving engineering.

4.4 Goals More Fundamental to Engineering

While analyzing the two interviews, we also realized that there are factors or "goals" more fundamental to engineering that in fact motivated both Sarah and Rebecca to leave engineering. These factors or goals shaped the ways they perceived engineering and what other non-engineering degrees they switched to. For instance, as a first generation college student, Sarah (and her family members as well) cared more about whether she could graduate on time and find a well-paid job. When consulting with her family members, Sarah found her family members supportive of her leaving engineering, despite that her family members "don't really care…as long as [she] is getting a degree that it's going to help [her] be able to make enough money." Therefore, Sarah ended up transferring to the cybersecurity major in the business school that was perceived to be less challenging but equally employable and profitable as engineering.

In comparison, Rebecca really enjoyed cooking, life, and family relationships. She was able to do a lot of cooking for the family during the COVID which used to be done by her grandmother, thus shifting her interests towards Food Sciences.

5 DISCUSSION

In contrast to the existing literature that focuses on either how Hispanic and Black students leave engineering and the factors that may lead to their departure, this paper presented some preliminary findings on the factors that caused Asian American students to leave engineering. Unlike the traditional model minority myth, some Asian American students did find themselves challenged by engineering cultures. First, for the two Asian American students in particular, some preliminary evidence showed that the lack of care, sympathy, and teaching effectiveness in courses with difficult, math-intensive concepts was a major reason for them to leave engineering. Second, the competitive environment of engineering disengaged students from meaningfully participating in engineering. The innovative, hands-on aspects of engineering did attract students but were later neutralized by the "competitive reality" of engineering which further caused mental health issues and the lack of diversity and creativity. Third, in addition to the formal engineering curriculum, institutional cultures such as the ways in which the university communicated to students about their performance and interactions between students and their peers and advisors may also affect students' determination to pursue engineering. Lastly, students all have different motivations to pursue engineering and therefore if their goals are not met they could potentially leave engineering. Future engineering education needs to help students navigate how their personal values are aligned with professional goals in engineering education.

These interviews unpacked the nuanced experiences and expectations of Asian American students to navigate the space of engineering. For future research, the intersections of various identities should be understood in order for better equity of all students in engineering and the lasting effects of COVID on students' academic performance. Perhaps the most important implication for research, generally and in engineering, is to disaggregate data on Asian Americans broadly in engineering, as subgroups of Asian Americans experience engineering differently. This is salient especially in thinking about policy and practical changes that could affect Asian American students in engineering.

As much of the literature in engineering makes the false assumption that all Asian Americans experience engineering the same, continuing to disaggregate Asian American data could help provide the needed resources for students. Another way that this research could help future generations of Asian American engineering students is by encouraging more funding towards programs that support Asian American cultural development. This could be seen through support for Asian cultural centers, living learning communities, or support for Asian and Asian American Studies at the university level.

5.1 Limitations

As our study is exploratory in nature, it is important to note some of its limitations. First, our two participants are female students. While we will try to diversify our student population as we continue this project, we want to note that there could be a gendered phenomena of those who chose to leave engineering. As Sarah indicated, the male dominated environment of engineering may be a reason why Asian American women may feel compelled to leave engineering (Castro and Collins

2019). In other words, we need to explore whether Asian American women are more likely to leave engineering than Asian American men. Second, part of our objectives for this study is to explore the feasibility of this project, including the interview protocol by experimenting with two participants. Doing so can help us further refine the interview protocol which will be included in our future research. Third, while we had hoped to find and include metrics to help strengthen our arguments, there have been no systematic data regarding this as retention is not a concept often found popular in studying Asian American students in engineering. Unfortunately, Asian Americans are considered, at least in the US context, a homogeneous group and therefore are considered overrepresented. Therefore, there has not been specific metric on this topic, but we hope that future engineering education researchers will consider this and include this population in future research on retention in engineering.

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THE POTENTIAL OF METAVERSE TECHNOLOGY IN E-LEARNING: CASE OF ENGINEERING STUDENTS

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ABSTRACT

Metaverse technology integrates virtual and augmented reality, has significantly impacted many industries, and opened up new opportunities for educators and

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learners alike. This article focuses on its potential to transform e-learning, especially in engineering education, and highlights the importance of understanding engineering students' attitudes toward adopting new technologies. This study sheds light on the potential of e-learning in general, and the metaverse in specific, to engage and motivate students.

We conducted a quantitative online survey (n=120) to collect data from engineering students. The analysis of collected data explores and evaluates the students' awareness and acceptance of the metaverse in e-learning. Our results demonstrate that engineering students have a good awareness, a positive attitude, and motivation towards using new technologies and highlight a good opportunity for the metaverse to enhance engineering students’ online interactions and participation compared with traditional e-learning methods.

We have identified several challenges and opportunities in using the metaverse in e-learning, including the need for new competencies, specialized hardware and software, and data privacy and security concerns. The paper concludes with recommendations for future research, emphasizing the benefits, e-learning's potential, and challenges of the metaverse in e-learning.

1 INTRODUCTION

Metaverse is a virtual environment where people can exist under the rules defined by the creator (Hwang and Chien 2022), it gives the impression that everything is real and physical; people can interact with each other and digital objects in a shared space without being bound by physical limitations, creating a highly immersive and engaging experience.

Numerous industries, including business, education, and entertainment, stand to benefit greatly from this new technology. Metaverse has been gaining traction in recent years as a potential game-changer in the realm of e-learning (Zhang et al. 2022). The application of the metaverse in Engineering Education (EE) is an emerging research topic that has rapidly gained the interest of many researchers (Hwang and Chien 2022). In this paper, our focus is on exploring the potential acceptance of "the metaverse" as an educational tool by engineering students.

The use of the metaverse in the field of EE bridges the gap between theory and practice enabling students to visualize complex concepts and engage in hands-on activities that simulate real-world scenarios. It allows engineering students to collaborate with their peers in a virtual space, allowing them to share ideas and work together on specific projects. For example, students can design and test virtual prototypes, experiment with different materials, and simulate the behavior of physical systems in a controlled environment such as virtual laboratories (Kaddoura and Al Husseiny 2023). Indeed, instead of just applying theoretical concepts to practical EE problems, the metaverse offers an environment where students can see the immediate results of their actions, making it easier for them to connect theory to practice and pursue careers in engineering.

Headsets are the most commonly used hardware component for an immersive metaverse experience and are therefore considered in this context as metaverse technology. However, there are other hardware components available that can enhance the experience further. These include Holographic Displays such as room, wall, or table displays, as well as Fans and Wind Simulation, Vibrating or Motion Platforms, and Haptic Feedback Suits (Dwivedi et al. 2022). While these components are available, they may not be widely accessible to students at present.

This study aims to investigate engineering students' attitudes towards and willingness to consider the metaverse as an alternative to traditional learning methods. The key research questions addressed in this study are as follows:

> RQ(1): What is the engineering students’ awareness and understanding of the metaverse?
> RQ(2): Is there a relationship between demographic factors and the willingness of engineering students to adopt the metaverse for e-learning?
> RQ(3): Does e-learning have an impact on the attitudes and behaviors of engineering students about adopting the metaverse?
> RQ(4): Is there a gap between the theoretical perspectives of the metaverse and its practical implementation?

2 LITERATURE REVIEW

E-learning is the process of delivering educational content and training programs through various electronic media (Koohang and Harman 2005). It is facilitated by Virtual Learning Environments (VLE), such as “Learning Management Systems”, “Course Management Systems”, or “Personal Learning Environments” (Li 2022). VLE have emerged as effective means of delivering education as they provide safe and engaging learning situations (Adolf et al. 2019). Integrating metaverse as a new VLE can significantly enhance the e-learning experience by creating immersive learning environments that enable learners to interact with the material more engagingly (Zhang et al. 2022). Metaverse offers several advantages over traditional methods, such as gamification, diversity, equity, and inclusion, which can improve learner motivation and critical thinking (Hwang and Chien 2022), (Zhang et al. 2022).

Despite their advancements, the metaverse allows the collection of highly specific personal user data such as physical conditions and facial recognition, which can also lead to a higher risk of data breaches and privacy violations. Privacy and data security, as well as social and ethical considerations regarding intellectual property rights abuse, are essential issues of the use of the metaverse as a new VLS (Zhang et al. 2022), (Kaddoura and Al Husseiny 2023). Moreover, integrating metaverse in EE requires participants' awareness and willingness to accept change and explore new technologies (Hwang and Chien 2022), (Zhang et al. 2022).

Regarding students’ awareness and understanding of the metaverse, Won et al. (2022) (Won et al. 2022) investigated engineering college teachers’ and students’ experience of using the metaverse for non-face-to-face (NFF) teaching and found that they are generally willing to use virtual reality-based NFF teaching and learning shortly even if they had no prior experience with it. A recent study by Salloum et al. (2023) showed that the students were aware of metaverse technology and considered metaverse-based educational platforms to have had a significant impact on their learning outcomes. The study also suggests that the use of metaverse technology has the potential to revolutionize the delivery of higher education (Salloum et al. 2023).

Concerning the eventual relationship between demographic factors and the willingness of engineering students to adopt the metaverse for e-learning, the study of Özdemir et al. (2022) concluded that male participants had higher metaverse knowledge, attitude, and awareness levels than females. A positive and weak relationship was found between the participants' average daily social media usage time and digitalization attitude (Özdemir et al. 2022). Furthermore, the results of Aburbeian et al. (2022) (Aburbeian et al. 2022) showed that males demonstrated more interest in metaverse technology than females. Additionally, participants under the age of 20 showed a greater interest in metaverse technology compared to other age groups (Aburbeian et al. 2022).

Many studies (Salloum et al. 2023), (Adolf et al. 2019), (Ghobadi et al. 2022), (Kaur et al. 2020) have explored the impact of metaverse technology on student attitudes and behaviors. They found that VR technology could increase students' interest, motivation, and engagement in learning. Kaur et al.(2020) investigated the effects of Augmented Reality (AR) on undergraduate students in electronics and electrical engineering and found that AR improved their attention, relevance, confidence, and satisfaction with the learning material in a classroom.

However, to the best of our knowledge, no dedicated study has explored the potential influence of demographic, behavioral, and attitudinal factors on engineering students' acceptance of the metaverse in e-learning. In this article, we aim to fill this research gap by examining the factors that affect engineering students' perceptions of the metaverse.

3 METHODOLOGY

3.1 Study context

In this article, we targeted opportunities to use the metaverse in the higher education sector for engineering students. To answer our research questions, we conducted, between February and April 2023, a quantitative online survey that was distributed to several engineering universities. We mainly investigated the awareness and satisfaction of engineering students regarding the adoption of new technologies, specifically focusing on the full immersion metaverse technology facilitated through specialised headsets.

We received 120 responses from engineering students. We took care to ensure that the students were fully informed about the purpose and utilisation of the data collected. We made it clear to them that the data would be used for research purposes. The participant’s demography shows that 65% were male, while 35% were female. As shown in Figure 1, mechanical and computer sciences students have registered the highest participation with 33% and 30% responses respectively.

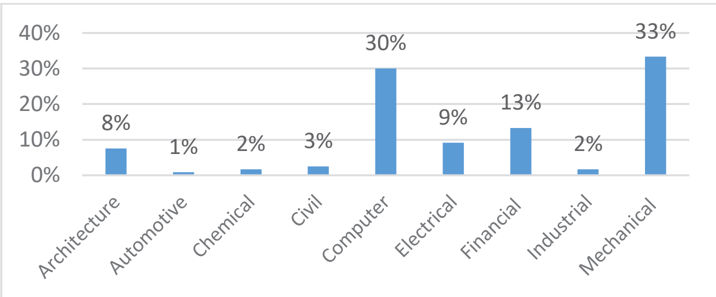

Fig. 1. Survey questions visualization for engineering majors’ percentage

Out of the 120 respondents, the highest participation was registered by undergraduate students (48% of the total participants). Following them were master's (29%) and Ph.D. degree students (23%).

We got 33% of responses from ages 21 and 23, 33% of responses from ages above 26 years, 19% of responses from ages between 24 and 26 years, and 15% of responses from ages less than 21.

We have outlined our study's objectives, confidentiality policy, participant confidentiality, data storage and processing, and other ethical considerations in the survey's introduction section.

The questionnaire was conducted with closed questions that mostly used the Likert 5-point scale. We addressed the attitude of students regarding e-learning and new technologies and the use of metaverse in the education sector. Some examples of survey questions include:

> I think that e-learning services have a positive impact on a student's ability to listen and concentrate : Strongly disagree; Somewhat disagree; Neutral; Somewhat agree; Strongly agree.
> Are you interested in learning about the metaverse and its potential applications in e-learning? : Not interested at all; Not really interested; Somewhat interested; Yes, interested; Yes, very interested.

To gather feedback on our survey design, a pre-test was conducted with a group of eight students. Based on their feedback and ideas for improvement, the survey was further developed and finalized. The survey was then distributed to all engineering students through email.

To address our fourth research question (RQ4), we selected a subset of eleven students who had used the metaverse in their undergraduate senior project. We recorded their answers separately and compared them with those of the complete sample obtained in the principal survey.

For data analysis, we employed statistical analysis (T-test, ANOVA, and Kruskal-Wallis) and utilized several artificial intelligence classifiers, including Decision Tree (DT), Support Vector Machines (SVM), Random Forest (RF), Logistic Regression (LR), and Gradient Boosting (GB).

4 RESULTS AND DISCUSSION

4.1 Level of awareness, experimentation, and willingness to adopt the metaverse

Our first research question (RQ1) aimed to investigate the level of awareness and understanding of the metaverse among engineering students. The survey data indicated that 65% of the participants had heard of the term "Metaverse," while 20% had heard of either VR or AR but not both together. Only 15% of the participants had never heard about the metaverse. These findings align with the findings of Salloum et al. (2023) (Salloum et al. 2023).

Among the 85% of participants who had prior awareness of virtual and/or augmented reality, 56% of them had not experimented with metaverse before. This finding suggests that although a significant number of participants had prior knowledge of VR and/or AR, they were not necessarily familiar with the metaverse.

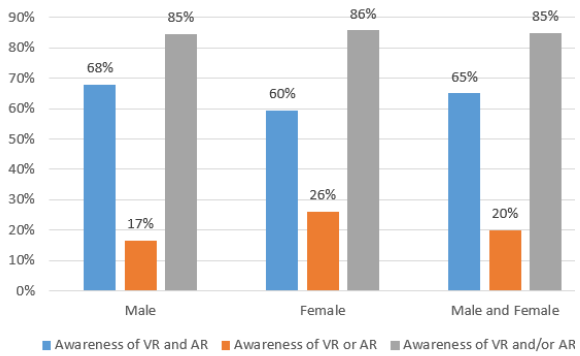

Fig. 2. Awareness of VR/ AR

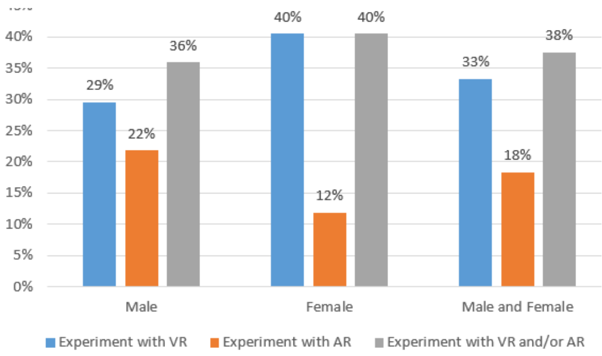

Fig. 3. Experimentation with VR/ AR

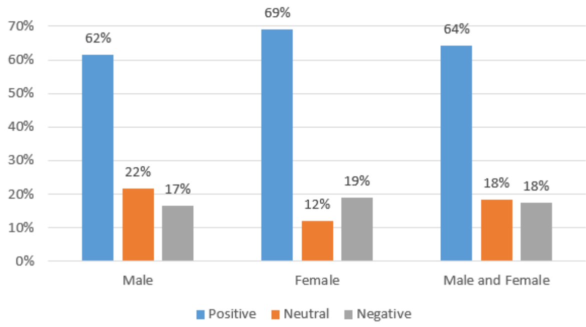

Fig. 4. Willingness to adopt the metaverse for e-learning

To further explore the distribution of awareness and experimentation of VR and/or AR regarding gender, figures 2, 3, and 4 present a description of the results. They provide a breakdown of the participant's gender and their level of awareness, experimentation, and willingness to adopt the metaverse.

4.2 Influence of demographic factors on engineering students' awareness, understanding, and willingness to adopt the metaverse

Our second research question (RQ2) aimed to gain a deeper understanding of the demographical factors that may influence the participants' level of awareness and understanding of the metaverse.

A statistical analysis using independent sample T-test for H0, H1 and H2, and Anova and Kruskal-Wallis tests for H3, H4 and H5 was performed to investigate the following hypotheses:

H0: there is a relation between gender and the metaverse's awareness level.
H1: there is a relation between gender and the experimentation of the metaverse.
H2: there is a relation between gender and the willingness of engineering students to adopt the metaverse for e-learning.
H3: there is a relation between the level of education and the level of awareness of the metaverse.
H4: there is a relation between the level of education and the experimentation of the metaverse.

H5: there is a relation between the level of education and the willingness of engineering students to adopt the metaverse for e-learning.

The results of the unpaired T-test showed that the p-values for H0, H1, and H2 were respectively 0.609, 0.855, and 0.212, all of which were greater than or equal to 0.05. Therefore, H0, H1, and H2 were rejected, indicating that there is no significant relation between the level of awareness, experimentation, and willingness to adopt the metaverse and gender. These findings differ from those presented by Özdemir et al. (2022) (Özdemir et al. 2022) and Aburbeian et al. (2022) (Aburbeian et al. 2022).

The ANOVA test showed that the p-values for H3 and H4 were, respectively 0.780, 0.816, greater than or equal to 0.05, meaning that these hypotheses were also rejected. However, the p-value for H5 was 0.021, which is less than 0.05, indicating that H5 was accepted. A similar result was obtained using the Kruskal-Wallis test.

Based on the analyzed sample, there was no significant relation between the level of awareness and the education level, nor between the experimentation of the metaverse and the education level. However, the willingness of engineering students to adopt the metaverse for e-learning was found to be directly correlated with the education level, with Ph.D. students showing the highest willingness to adopt e-learning compared to master and undergraduate students.

4.3 Relation between engineering students' Attitudes and their willingness to adopt the metaverse in Education

Our results indicate that engineering students hold positive attitudes toward the metaverse and are willing to learn more about it. A significant proportion of students (64%) expressed interest in exploring the use of the metaverse in education, as demonstrated in Fig.4. Additionally, 64% of the participants rated staying informed about new technologies as an extremely important aspect of their education. 44% of the participants thought that incorporating the metaverse into e-learning environments would enhance engagement and enjoyment, compared to only 3% who disagreed.

Our third research question (RQ3) aimed to further explore the relationship between students’ attitudes toward e-learning and their propensity to adopt the metaverse. To achieve this and better understand which factor affects the others we examined the potential correlation between the students' e-learning experience, their level of technological knowledge, and their willingness to integrate the metaverse into the education sector.

During the analysis stage, we employed the Pearson correlation coefficient to assess the relationship between different variables that could potentially affect the adoption of the metaverse in e-learning. We utilized multiple linear regression techniques with forward selection methods. The correlation coefficient should ideally deviate from zero, indicating a positive or negative relationship, and approach values of 1 or -1. For instance, a correlation between variables is considered weak if the absolute coefficient lies between 0.3 and 0.5, moderate if between 0.5 and 0.7, and strong if greater than 0.7.

	A -	B -	C -	D -	E -	F -	G -	H -	I -
A- Time spent online per day	1								
B- Level of understanding of new technologies	0.0	1							
C- Importance of staying informed about technologies	0.1	0.3	1						
D- Experience of internet weakness with e-learning	0.1	0.0	0.0	1					
E- Experience difficulty with e-learning tools	0.1	0.0	0.1	0.4	1				
F- E-learning improves listening and concentration	0.2	0.2	0.4	0.0	0.1	1			
G- Satisfaction with e-learning	0.0	0.2	0.2	-0.2	0.0	0.5	1		
H- Interest in using metaverse in e-learning	0.2	0.1	0.5	0.1	0.1	0.3	0.2	1	
I- Metaverse e-learning is more engaging	0.2	0.3	0.2	-0.1	0.0	0.2	0.3	0.5	1

Fig. 5. Corrolation Matrix

As shown in Figure 5, for instance, there is a weak positive correlation between the level of understanding of new technologies and the positive estimation of the metaverse as an engaging technique for e-learning. Additionally, a moderate positive correlation exists between the importance of staying informed about new technologies and the interest in using the metaverse in e-learning.

Additionally, we applied five well-known artificial intelligence classifiers (DT, SVM, RF, LR, and GB) using Python to predict the degree of "student's interest in using the metaverse in e-learning" based on other attitudes and behavioral features. The purpose of these classifiers is to provide a meaningful number (between 0 and 3) that accurately predicts the label "student's interest in using the metaverse in e-learning". We divided the data into training (80%) and testing (20%) sets.

Figure 6. displays the accuracy of predicting "student's interest in using the metaverse in e-learning" for each classifier. The Support Vector Machines classifier achieved the highest accuracy, with a good prediction accuracy of 87%, followed by the LR and RF classifiers at 80%, and the GB classifier at 73%. The DT classifier had the lowest accuracy, with only a 47% prediction accuracy.

The high accuracy of 87% achieved by the SVM classifier in predicting students' interest in using the metaverse for e-learning is significant. It means that the model was able to correctly classify 87% of the test data based on their attitudes and behaviors towards using the metaverse in e-learning. This indicates that the selected features (attitudes and behaviors of engineering students) have a strong influence on predicting students' interest in using the metaverse in e-learning. Therefore, this model can be used as a reliable tool to predict students' interest in using the metaverse for e-learning.

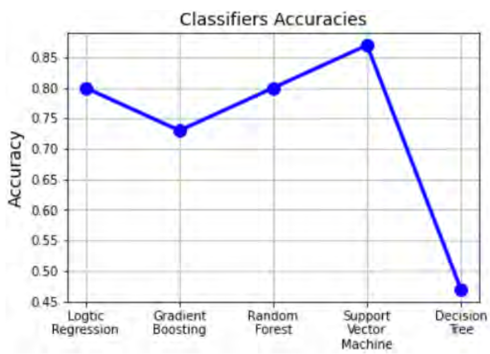

Fig. 6. Accuricies of AI classifiers

4.4 Experimented perception versus general knowledge perception

To answer RQ4 and fill the gap between theory and practice, the general survey used to collect data from random engineering students was compared with another survey gathering data from a group of 11 engineering students who had already worked on the development of a VR environment using Unity in their undergraduate senior projects. The 11 students were involved in three different groups to create three VR applications for academic purposes. The metaverse technology used to visualize these projects was mainly the Oculus Quest headset and controllers.

Data analysis of the selected sample compared with the general sample reveals a significant difference in the influence of the metaverse to offer a more engaging and motivated environment for learning. All users of the selected sample considered the potential of the metaverse to engage students and enhance e-learning involvement and interaction to be extremely important. Specifically, 73% of them reported that the main reason for engagement is the need for direct interaction with the educational virtual environment and the potential of metaverse technologies and tools to isolate the student from external distractions.

We conducted a statistical analysis using an independent sample T-test to investigate the following hypotheses :

> H6: there is a relation between the level of expertise and practice of the metaverse and considering metaverse-based e-learning environment more engaging and enjoyable than traditional e-learning methods.
> H7: there is a relation between the level of expertise and practice of the metaverse and considering that the metaverse has the potential to revolutionize the way students learn and practice their skills.

The results of the T-test showed that the p-values for H6 and H7 were less than 0.05. Therefore, H6 and H7 were accepted and statistically proven.

5 CONCLUSION

This study examines the potential influence of metaverse in EE and highlights the importance of understanding engineering students' attitudes toward adopting this technology. We surveyed to investigate engineering students' attitudes and demographical factors towards and willingness to adopt the metaverse in EE.

Our results illustrate that engineering students have a good awareness, positive attitude, and motivation towards using the metaverse in e-learning. We found that the only demographical factor that impacts the willingness of using the metaverse in e-learning is the student's academic level. Also, we found a positive correlation between the willingness of staying informed about new technologies and the willingness to use the metaverse in e-learning. Moreover, the level of expertise and practice of the metaverse positively relates to considering metaverse-based e-learning environments more engaging and motivating than traditional ones.

Based on these results, educational engineering institutions could take advantage of the positive attitudes and motivations of engineering students towards using the metaverse, and invest in programs that allow students to gain expertise and practice in using it. This could involve introducing the metaverse early on in the engineering curriculum and creating metaverse-based e-learning environments.

However, challenges still exist regarding the selection of materials to be included in the metaverse environment, as different engineering majors may require specialized metaverse technologies and configurations. Data privacy and security concerns also require further investigation. Moreover, although promising results were obtained in this preliminary study, we expect that a larger survey size will further enhance our findings.

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AI FOR LEADERSHIP: IMPLEMENTATION AND EVALUATION OF AN AI EDUCATIONAL PROGRAM

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ABSTRACT

AI education is rapidly becoming the next frontier when it comes to solving the world's grand challenges; however, ways to introduce AI to large complex organisations are still vastly understudied. To address this gap in 2021, Massachusetts Institute of Technology (MIT) entered into a collaboration with the US Air Force (USAF). The goal of this relationship is to develop, study, and evaluate different learning modalities and online/in-person experiences to introduce AI to the diverse USAF workforce. The USAF is a very complex organisation and its employees vary in terms of educational and cultural backgrounds, as well as in their work-related needs, demands and restrictions.

The initial program started in 2021 and a pilot study took place. The pilot evaluated the content, pedagogy, and educational technology used in 3 different learning journeys designed for 6 different learner profiles. Findings from 2021 guided improvements for future iterations. The updated iteration of the learning journey was introduced to the second cohort of the program in 2022. Cohort 2 included 200 USAF leaders, managers and decision makers, and the learning journey consisted of a combination of synchronous and asynchronous online experiences, as well as an in-person active learning component offered on campus to a subgroup of the learners. This research paper will introduce the updated iteration of the program, the evaluation of the learning journey, as well as the overall learner experience.

1 INTRODUCTION

As educational institutions are working towards understanding how to best educate the next generations of engineers and scientists in order to achieve the Sustainable Development Goals (SDGs), Artificial Intelligence (AI) is considered by many a tool that will considerably contribute to this goal [1,2]. Although AI will inevitably shape most professional sectors along with the ways most organisations will operate , potential impacts so far indicate both positive and negative expected impacts on sustainable development [3,4], making proper education for and about AI critical and relative to all academic fields.

Despite the rapid development at the AI forefront, education for and about AI, along with expected impact and ethical considerations, is still at a nascent stage and largely understudied. With the goal to better understand optimal ways regarding AI education, in 2021 the United States Air Force (USAF) and the Department of Defense (DoD) entered into a collaboration with multiple units within the Massachusetts Institute of Technology (MIT) to develop, pilot, and study a new academic program focusing on AI training. "Given the size and the diversity within the body of USAF employees, the goal of this collaboration is to design and implement an innovative program that will achieve maximum learning outcomes at scale for learners with diverse roles and educational backgrounds" [5] ranging from Air Force and Department of Defense (DoD) personnel to the general public.

2 AI EDUCATION PROGRAM DEVELOPMENT

2.1 Background

To start this new research program, the Joint Artificial Intelligence Center (JAIC) conducted a primary analysis of the US Air Force (USAF) personnel and created 6 learner profiles (also mentioned as “archetypes”), along with a list of desired AI related needs, skills and competencies for each one of them, and they are presented in great detail in the [6] JAIC report. In 2021, based on this information, a team that consisted of USAF representatives and MIT experts in AI and STEM Curriculum Development, developed 3 different 9 month-long learning journeys that were offered to the first learner cohort. This cohort included 3 different groups of learners: a) the Lead AI and Drive AI archetypes (L/D) - traditionally focusing more on management and leadership of the organisation, b) the Create AI and Embed AI (C/E) - being mostly technology developers and facilitators, and c) learners from Facilitate AI and Employ AI (F/E) - who are mainly AI technology end users [5]. The different learning journeys included a variety of courses and educational resources, offered through different learning modalities, representing content at different levels of difficulty. The various learning modalities included online asynchronous self-paced content, online asynchronous instructor-paced content, experimental online and in-person courses, along with participation in live online events with AI experts. A research team conducted a first pilot evaluation aiming to understand the learner perspective in regards to content, pedagogy, and technology used in the program, as well as the overall learner experience. To support the AI Education research program, a portal was also developed to support each learning journey and provide access to some of the content, but users often had to register to multiple platforms since courses were offered by different MIT teams. Details about program development, desired learning outcomes, implementation details, along with research findings from the first pilot evaluation are described in great detail in [5,7]

Feedback from the pilot study had highlighted some challenges regarding the long duration of the program, accessibility issues with the technology, occasional difficulty with the content, limited direct relevance of the content with the DoD daily operations and to real life application, and in some cases, learners mentioned that they wanted more real-life connections to experts/peers. Furthermore, additional feedback was provided by MIT experts, who were asked to review the curricula and perform a gap analysis, and by learning experts who offered pedagogical recommendations.

2.2 Second Iteration - Fall 2022

Based on feedback from the first pilot, the development team implemented several improvements on content, pedagogy, and technology and offered a new learning journey to a second cohort of 200 L/D learners in the Fall of 2022. This was a shorter, 3-months long, program. Figure 1 presents the second L/D learning journey.

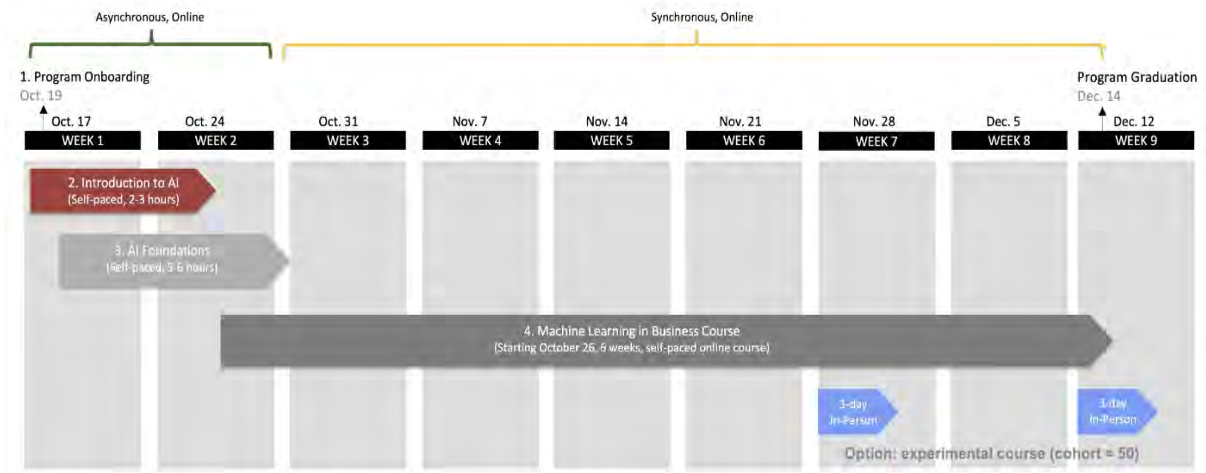

Fig. 1. Revised Lead/Drive Learning Journey - Fall 2022.

In the beginning of the program, all learners had access to two separate asynchronous self-paced courses, which involved reading content and watching videos: a) *Introduction to AI* (with content requiring 5-10 min per topic, and expected to be completely covered in 2-3 hours) and b) *AI Foundations* (with content requiring 10 minutes per topic, and expected to be fully covered in 5-6 hours). The cohort then had to follow the 8-weeks long, instructor paced, online *Machine Learning in Business* course. A small number of the learners were also selected (~40) by the USAF to visit the MIT campus and participated in the in-person hands-on intense 3-day long *Learning Machines: Computation, Ethics, and Policy workshop*, along with learners from other DoD offices (two workshops for ~20 learners each). Since this workshop included a new mixed group of learners, the research team decided to treat it as a separate class and performed a separate evaluation study.

Based on feedback from the pilot study, the following improvements, as presented in Table 1, were made to the *Introduction to AI* course and to the learning portal.

Table 1. Introduction to AI Course and AI Education Portal Improvements

Content	● AI topic content updated. ● Added "Impact Spotlights" between different modules (mini case studies about how AI is being applied to solve real world challenges). ● Added "Technology Spotlights" between different modules (new content element within articles that calls out specific details about a technology and how it works).
Pedagogy	● Added knowledge checks embedded throughout articles to support retrieval effect. ● Added "Impact spotlights" (mini case examples) to support learning reinforcement.
Technology	● Improved portal homepage experience was added. ● Knowledge checks were embedded at the end of articles. ● New UI for impact spotlights was created.

Similar to the first pilot program for the L/D archetypes, desired learning outcomes remain the same, namely learning about: foundational concepts, AI application, data management, responsible AI, AI delivery, and AI Enablement. In greater detail the second program iteration covered AI basics, how AI works, benefits and limitations, common misconceptions, recent developments, uses of AI in industry, case studies relevant to the USAF and DoD, the future of AI, and a primer in AI ethics.

3 METHODOLOGY

3.1 Data Collection and Analysis

All research material, instruments and procedures were approved by the MIT (COUHES) and Air Force (HRPO) IRB offices. All personnel received commander approval prior to their participation in the program's research component.
The research team designed and delivered a pre-questionnaire (baseline assessment) and a final exit post-questionnaire offered to the 200 learners. The pre-questionnaire sought to understand learner demographics and educational level, as well as prior familiarity with AI related content, pedagogies that will be implemented during the program, and educational technology the learners will be asked to use. Furthermore, they had to answer questions about their own personal interest in AI. After completion of the program, the post-questionnaire asked learners to self-report their perception about the AI content, the pedagogies and technologies employed, and engagement and success regarding learning goals. For situations where participants were unable to complete a course, they were asked the reasons for dropping out. Additional questions about the program interest, relevance to work, and the overall learner experience were included as well. A total of 178 (89%) of the learners completed the pre-questionnaire, and 51 of them (25.5%) completed the post-questionnaire. Descriptive statistics were used to analyse the data.

4 RESULTS

4.1 Completion Rates

Table 2 presents the completion rates of the 3 courses offered to cohort 2. In this cohort 149 learners (83%) identified as male, 26 (14%) female, 1 (1%) transgender, and 3 (2%), prefer not to respond to this question. It should be noted that the pre-questionnaire showed that 142 learners (79%) had a Masters or PhD degree, with a great number coming from STEM schools.

Table 2. Completion rates

Introduction to AI & *AI Fundamentals*	183 (~92%) participants logged on to the platform at least once. 173 (~87%) active participants (read one or more articles). 121 (~61%) active participants completed all content (including videos).

Machine Learning for Business	173 (~87%) active participants. 160 (80%) completion rate (read one or more of the articles). 160 (80%) got certificates.
Complete Learning Journey	70% of active participants completed the entire journey (452,734 total learning minutes). Certificates: to those who completed 90%+ of the learning journey.

4.2 Research Findings

Basic AI knowledge and familiarity with its uses and applications are core program learning outcomes, suggesting the competencies gained by learners. Upon completion of the program, as presented in Figure 2, 75% of the respondents (39 learners) expressed that they now feel above average familiarity with AI concepts.

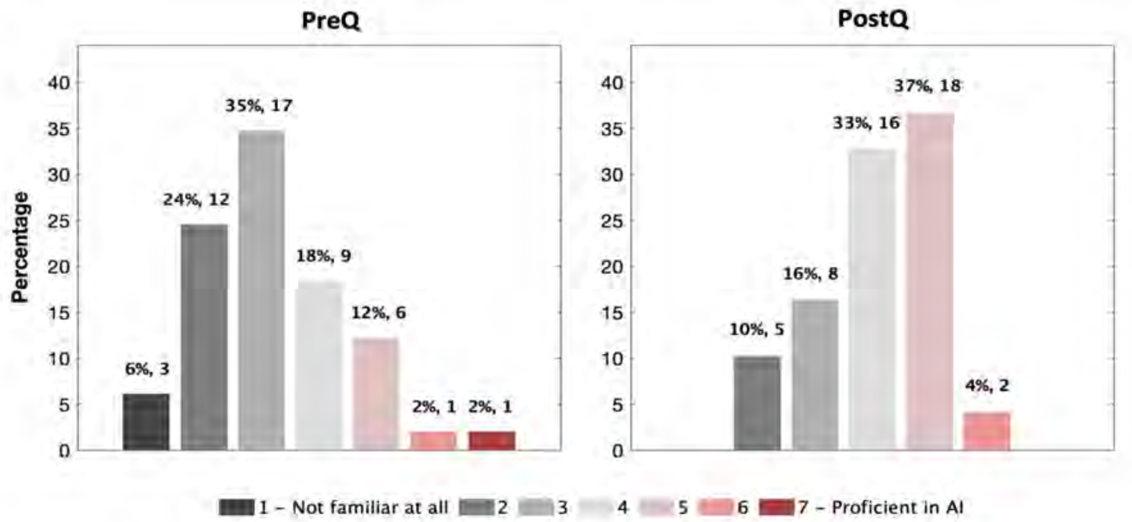

Fig. 2. Familiarity with AI: Comparative plots representing pre- and post-questionnaire responses (percentage, response count), respectively

Learners were also asked to discuss their overall experience with the program. As presented in Figure 3, 93% of respondents (47 learners) would recommend the program to a colleague. More specifically, they were asked to comment on whether they found the program interesting and relevant to their work. When discussing interest, as presented in Figure 4, 100% of the learners that responded to the post-questionnaire (51) found the program to be above average levels of interest with 81% (42) rating the program very high. When discussing the relevance of the program to the work of DoD (Figure 5), 87% (45) could see relevance, while 31% (16) found the program to be very relevant to their current work. From a pedagogical perspective, when asked to discuss the portal, 61% (31 learners) of the post-questionnaire respondents mentioned revisiting prior content on the portal throughout the duration of the program to refresh their memory. These first indicators suggest the program aligns with the learner training needs and the program goals.

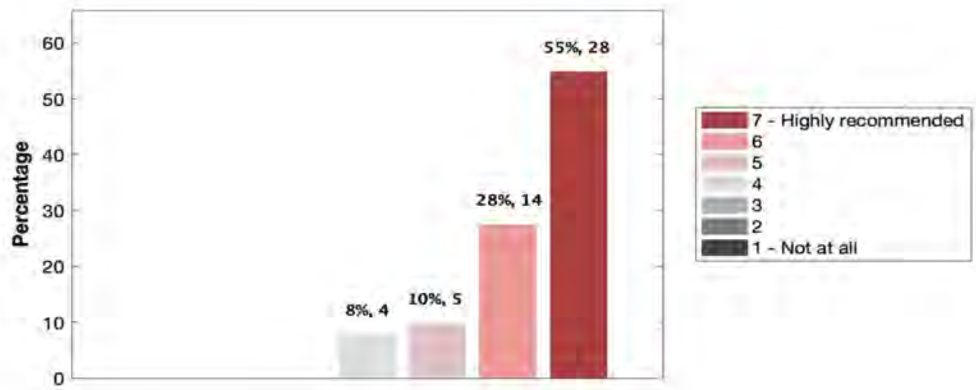

Fig. 3. Recommend program to a colleague

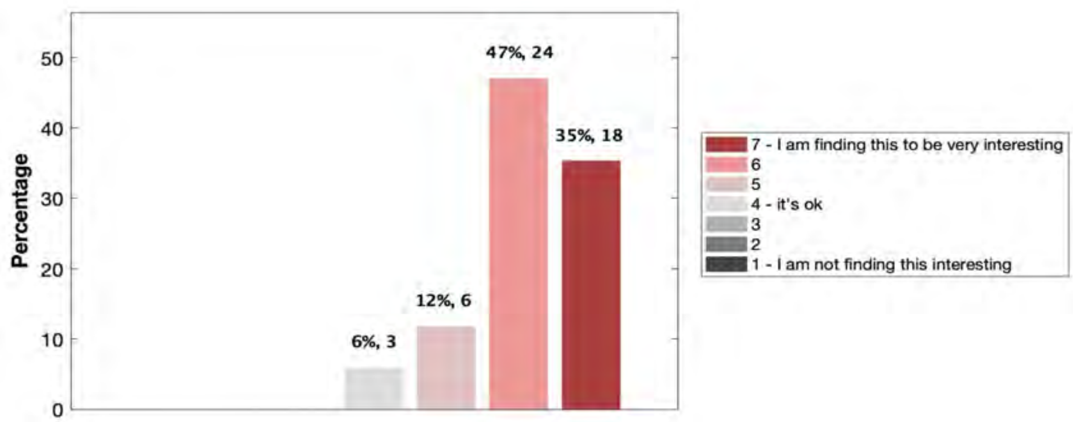

Fig. 4. Interest to the AI program

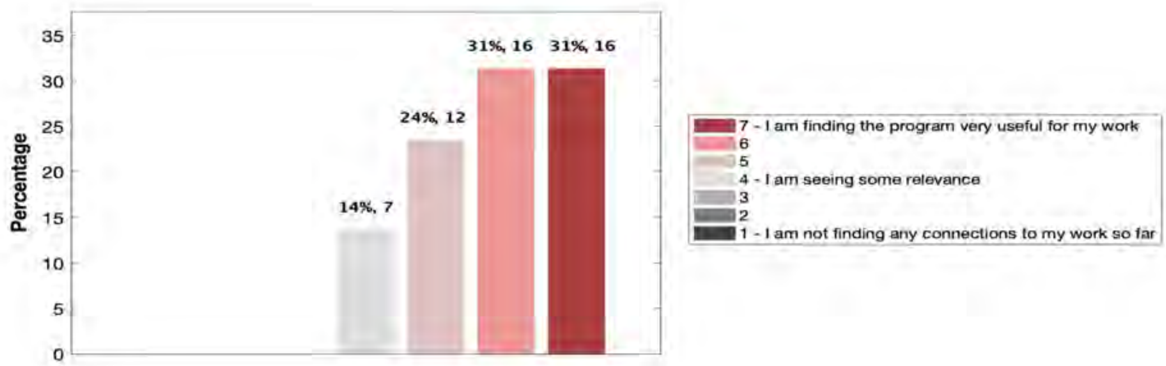

Fig. 5. Relevance to DoD work

5 FUTURE WORK

The development team is now experimenting with 2 different courses (one digital and one in-person) offered again to small groups of L/D participants. They are also preparing to experiment with an online, asynchronous, offering to a much larger cohort in the future to better study scaling to large numbers. In the meantime, the team is using feedback received from the first two cohorts to implement further improvements in regards to content, pedagogy and technology while the research team also plans to assess key AI-related ethical considerations, including safety, privacy, explainability, fairness, and externalities. Table 2 presents improvements that are currently under development.

Table 2. Introduction to AI Course and AI Education Portal Future Improvements

Content	● AI topic content updated to include Generative AI and other recent AI developments. Currently also exploring the intersection of digital tech (AI, big data, cloud etc) and sustainability. ● More Impact Spotlights - mini case studies about how AI is being applied to solve real world challenges. ● Reflection questions added to community forum sections.
Pedagogy	● A knowledge check at the end of the journey rather than embedded to improve technical experience. ● Added “Impact spotlights” library (mini case examples) to support learning reinforcement. ● Addition of community forum sections per topic to promote peer-to-peer learning.
Technology	● Improved portal homepage experience was added with a user profile. ● New, clearer, user interface for knowledge checks was created. ● New filterable tool for impact spotlights was created. ● Developed a forum functionality to support reflection questions and community engagement.

Furthermore, based on learners’ feedback, improvement is now considered in four broader areas: accessibility, scalability, support, and implementation. Regarding accessibility, all content needs to become accessible through the whole military network (some resources are still getting blocked so learners have to access on personal devices at home). About scalability, more scalable active learning and hands-on activities are necessary. For better support online learning communities and additional staffing is considered. Last but not least, it is considered a good time for USAF leadership to start shifting from learning about AI to start investing in the adoption and implementation of ML/AI technologies at work. All the above topics will help us further measure and understand future impact.

6 ACKNOWLEDGMENTS

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Democratic Education within the standard curriculum at Technische Universität Berlin. A quantitative analysis.

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ABSTRACT

Introduction - Technische Universität Berlin (TU Berlin) was founded after the Second World War on the ruins of its predecessor. At its inauguration it was bound to promote democracy through its education. This view is further held up through the university law of the federal state of Berlin which states that the disciplinary competences are to be acquired in such a way so that students are able to act democratically. This spirit is still alive at TU Berlin and over the past decades it led to several educational concepts which reach beyond traditional methods of teaching/learning and which expand the limits of what is seen as classical content. Yet, a closer examination is needed as to what role democracy plays within higher education at TU Berlin.

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Methods - A quantitative research provides descriptive statistics as to how many times the words “democracy” or “democratic” show up in study programs and modules. A limitation to these two terms is appropriate as they are the most comprehensive terms in comparison to others like participation or inclusion.

Results - The initial research shows that the two terms only show up in 3 out of 130 study programs as well as in only 16 modules out of thousands of modules.

Discussion - The curriculum at TU Berlin shows almost a clear lack of democracy/democratic education. An extension of this research to other universities is already on its way.

1 INTRODUCTION

1.1 Research Question

With regard to staff, students and budget, Technische Universität Berlin (TU Berlin) is one of the largest public universities within Germany with around 33.000 students, 4.000 persons of academic staff as well as a budget of 563 Mio. Euros. TU Berlin has a clear focus on STEM study programs. However, there is also a significant focus on humanities, education, architecture and planning. The predecessor of TU Berlin was well integrated into Nazi Germany with a staff which in general upheld facism, antisemitism and significantly contributed to war technology research (Baganz 2013). After the Second World War TU Berlin was founded anew on the ruins of its predecessor. All four allies jointly ruled that TU Berlin has to integrate an education for responsibility and democracy within the science and engineering study programs (König 1996).

Before this background, the general research question for this paper is the following:

- What is the current role of democratic education within higher education at TU Berlin?

There has been no prior research on this topic. Therefore, this paper is a first exploratory analysis which covers only a quantitative analysis of the study programs and modules offered at TU Berlin. This first analysis is limited to the terms “democracy” and “democratic” as they are the most comprehensive terms. There are numerous concepts that are typically linked to democracy. However, they are only derived from it, such as participation and deliberation and thus they are already weakening its meaning in one way or another. Similar applies to the different values that are seen as democratic, such as freedom and equality. Therefore, this research project is based on the assumption that only when either the term “democracy” or “democratic” is used in a regulation of a study program or a module description, it can be assumed that the terms are used with regard to their full meaning.

Thus, the initial research question is split into two and specified as follows:

- How many times are the words “democracy” or “democratic” mentioned in the regulations of the study programs at TU Berlin? How are these words used and In which contexts?
- How many times are the words “democracy” or “democratic” mentioned in the modules offered at TU Berlin? How are these words used and In which contexts?

1.2 State University Law

TU Berlin is one of four public universities in the federal state of Berlin in Germany. In addition, there are several public universities of applied sciences including the universities of arts as well as numerous private universities. All of them are bound by the University Law of Berlin from 2011 including all subsequent changes (2011). This law provides a comprehensive framework which provides a clear understanding of the limits of the university's autonomy with regard to its governance, research as well as education. The following two quotes show that the universities in Berlin are charged with the concrete mission to contribute to democracy:

> “The universities serve the cultivation and development of science and art through research, teaching and study and the preparation for professional activities. In doing so, they contribute to the preservation of the democratic and social constitutional state and to the realisation of the constitutional values...” § 4, 1 (Berlin 2011)

This quote is taken from § 4 which is titled “Mission/Duties of the Universities”. It clearly states that universities have a double function with regard to democracy. First, they are to preserve and safeguard the existing status of democracy and second, they are to contribute to “the realisation of the constitutional values” which implies an analysis of the current status of democracy and the further democratisation of society.

With regard to the study programs in general, the legislator describe concrete objectives:

> “Education and studies should prepare students for professional activities, taking into account the changes in the professional world, and provide them with the necessary professional competencies, skills and methods in such a way that they are enabled to work scientifically or artistically, to think critically and to act freely, responsibly, ethically, democratically, sustainably and socially. [...]” § 21, 1 (Berlin 2011).

This quote is taken from § 21 which is titled “General objectives of studies”. On the one hand, with 55 words it is a good example for the remarkably long sentences that are widespread within the German language. On the other hand, as it is only one sentence it is made quite clear by the legislator that to “act democratically” is not a mere addition to the scientific or artistic study programs but that it is on an equal level. Therefore, students should acquire the competences of their respective academic domains all the while they should also acquire competences in order to “act democratically”.

1.3 Regulations, statements etc. at TU Berlin

The opening ceremony of TU Berlin in 1946 took place in the main building of the predecessor which was almost fully destroyed during the war. Therefore, the new foundation of TU Berlin was done in direct sight of parts of the destruction that Nazi Germany caused. The Opening Speech of TU Berlin was held by the British Major-General Eric P. Nares (1946) who addresses the effects of facism in general and charges the academic staff and students to take up their responsibility as he sees responsibility as the corner-stone of democracy. For him, this call for responsibility in direct relation to democracy has direct implications to an academic education which he spells out quite clearly:

> "[...] all education, technical, humanistic, or what you will, is universal: that is to say it must embrace the whole of man, the whole personality, and its first aim is to produce a whole human being, capable of taking his place responsibly beside his fellows in a community. Its second aim may be to produce a good philologist, a good architect, a good musician or a good engineer. But if education does not assist the development of the whole personality it fails in its aim, and this Technical University must not fail in its aim. [...] You have a big job ahead to achieve this. And you will only do it by observing the principles of Truth and true democracy." (Nares 1946)

It seems that the opening speech is the only official document of TU Berlin that lays out its overall objectives and picks up the terms "democracy" and "democratic". Neither the current mission statement of TU Berlin (2011) nor the mission statement for teaching at TU Berlin (2018) nor the TU Berlin Future Perspectives Until 2025 (2020a) make use of these terms. However, quite frequently terms like academic freedom, equality of opportunities, gender equality, diversity, sustainability and the like are used.

In a similar way, this also applies for the general study and exam regulations (TU Berlin 2020b) which provides the overall framework in which all study programs at TU Berlin have to work. Here as well, neither the term "democracy" nor the term "democratic" is used.

2 METHODOLOGY

2.1 Study Programs - Data Collection and Analysis

All study programs offered at TU Berlin must be based on the Berlin university law (2011) as well as the general study and exam regulations of TU Berlin (2020b). Building up on this general regulatory framework specific study and exam regulations are worked out for every study program. All study programs of TU Berlin are listed on a free accessible website (2022a) along with their specific study and exam regulations.

The following criteria are used to include the specific regulations for the quantitative analysis: Included are all study programs offered at TU Berlin which i) are completed either with a bachelor or a master degree, with the exception of ii) paid study programs as well as iii) study programs that are offered jointly with one or more other universities.

The selected study programs are then searched with the string *demok* as well as with the string *democ*. The two strings cover the German terms “demokratisch” and “Demokratie” as well as the English terms “democratic” and “democracy”. In addition, the two chosen search strings will also include words that contain the given strings such as Basisdemokratie (grassroots democracy). All hits are then carefully analysed whether they are referring to the concept of democracy which results in their inclusion for the further quantitative analysis or their respective exclusion. The selection was conducted in the summer semester 2022.

2.2 Module Description - Data Collection and Analysis

All modules offered at TU Berlin are listed in a freely accessible database (TU Berlin 2022b). All modules that are listed during the summer semester 2022 are included in the data analysis. This also includes modules that are not taught in this semester or in fact even modules that have not been taught for some years or which might have never been taught.

In a similar way as described above for the study programs, all modules listed in the database during the summer semester 2022 are then searched with the string *demok* as well as with the string *democ*. Accordingly, these modules are then either included in or excluded from the further data analysis.

3 RESULTS

3.1 Study Programs

Only three study program regulations at TU Berlin mention either the term democracy or the term democratic in any way, see table 1. All three study programs are offered by Faculty I which comprises the humanities and educational sciences. In addition to the number of hits with the regulations the number of students is given for each faculty and study program respectively which allows one to see how many students are affected by the inclusion of democracy within the study program regulation.

There is only one hit in each of the three study programs so a direct quote is given to illustrate in what way the term democracy is used. All quotes are translated from German to English.

M.A. Interdisciplinary Research on Antisemitism - "They [graduates] are qualified for [...] work in [...] organisations working for a democratic society.” (TU Berlin 2022c)

B.A. Culture and Technology - Educational Science - “Graduates understand the quality of education and justice in education as key challenges of modern and democratic societies in the context of technology and culture.” (TU Berlin 2022d)

M.A. Theory and History of Science and Technology - “Last but not least, they [the graduates] are proficient in evaluating the design of options for practical action critically and thereby promoting a free, accountable, democratic, social and ethically justifiable scientific-technical and political-social practice.” (TU Berlin 2022e)

The meagre number of results is further underlined by two meagre uses of the term democracy as it used 1) to describe a workplace and 2) to describe the object of the low level of competence of understanding. Only in the third case the term democracy is used with the high ranking competences of evaluating and promoting.

Table 1. Hits in study programs regulations.(Concise) sorting by faculties including the number of students enrolled in the study programs.

Study programs	# of study programs	# of enrolled students	# of hits
Faculty I - Humanities and Educational Sciences	**16**	**1709**	**3**
M.A. Interdisciplinary Research on Antisemitism		135	1
B.A. Culture and Technology - Educational Science		111	1
M.A. Theory and History of Science and Technology		81	1
Faculty II - Mathematics and Natural Sciences	**15**	**3727**	**0**
Faculty III - Process Sciences	**16**	**3443**	**0**
Faculty IV - Electrical Engineering and Computer Science	**15**	**6387**	**0**
Faculty V - Mechanical Engineering and Transport Systems	**16**	**5096**	**0**
Faculty VI - Planning Building Environment	**23**	**4562**	**0**
Faculty VII - Economics and Management	**8**	**3900**	**0**
School of Education - Central Institute	**23**	**916**	**0**
Total	**130**	**29740**	**3**

3.2 Module Descriptions

In summer semester 2022 a total of 16 modules had a reference to democracy, see table 2. Only three modules were listed as compulsory modules in one or more study programs, nine modules were listed as a compulsory elective in one or more study programs and four were only offered as a free elective.

The total number of modules offered in a particular semester cannot be determined through the user interface of the database. However, the total number will easily be in the thousands. Therefore, only a tiny percentage of modules offered at TU Berlin are addressing democracy in general. It needs to be pointed out that two out of 16 modules use the term democracy only in the literature list, so it is questionable whether here democratic education (Sant 2019) actually takes place within the module. This might also apply to some of the other modules as only six modules make use of the term in their learning outcomes and only two of these six modules use the term in a learning outcome as well as in the content or method section. However, seven out 16 modules are a compulsory course in at least one study program while five out 16 modules are a compulsory elective in at least one study program and four courses are merely an elective.

Table 2. Number and context of hit in module descriptions. Shortened quotation.
** translated from German to English*

Module title	Title	Outcome	Content	Method	Literature
Faculty I - Humanities and Educational Sciences			**2**	**2**	
Alternatives to Platform Capitalism				1	
Sustainable prints - Digital educational game with increasing impact				1	
Public space and urban culture			1		
Public, Communication and Media			1		
Faculty II - Mathematics and Natural Sciences					
Faculty III - Process Sciences					
Faculty IV - Electrical Eng. and Computer Science	**1**	**1**	**1**		
Theoretical Foundations of Digital Democracy	1	1	1		
Faculty V - Mechanical Eng. and Transport Systems		**4**	**2**		**1**
Aviation Security		1			
Development Methods for Sustainable Products					1
Critical Sustainability		1	1		
Sustainable Product Development - Blue Engineering		1			
Blue Engineering - Sustainability in Engineering		1			
Faculty VI - Planning Building Environment			**2**		
Global Environmental Governance			1		
Landscape development and environmental assessment designs			1		
Faculty VII - Economics and Management		**1**	**1**	**1**	**1**
Infrastructure and competition policy			1		
Public finances I: Efficient and sustainable fiscal policy					1
Organisation and Innovation Management		1			
Future Workshop				1	
School of Education - Central Institute					
Total	**1**	**6**	**7**	**3**	**2**

4 DISCUSSION AND SUMMARY

The results of this basic quantitative analysis clearly show that both terms are rarely used. Thus it is at least questionable whether the students of TU Berlin participate in a democratic education and thus acquire the competence to act democratically. It is also questionable whether TU Berlin fulfils its duty as it is described by the same law. Accordingly, this research project will be extended over the coming semesters

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FINNISH TECHNOLOGY STUDENTS' BELONGING IN TECHNOLOGY

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ABSTRACT

This paper examines Finnish technology students' belonging in technology. The

phenomenon is studied at the level of the field (belonging in the field of technology) and at the level of institution (belonging in one's study community). The data were collected within the annual student survey conducted by a professional organization for academic engineers in 2022, and analysed statistically. Results suggest that men strongly experience they belong in technology while women express some doubts, and non-binary respondents are even less certain of their belonging. Gender differences in belonging in the field of technology are more prominent than those of belonging in the student community.

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1 INTRODUCTION

Sense of belonging has been defined as “the subjective feeling of fitting in and being included as a valued and legitimate member in a particular setting” (Lewis et al. 2017) and as “a self-representation that indicates how much students see themselves as fitting in with those around them” (Master and Meltzoff 2020). As a theoretical concept, it has been used to explain for example students’ motivation and persistence in education (Tinto 2017), gender differences in persistence in engineering (González-Pérez et al. 2022), gender gaps in STEM (Master and Meltzoff 2020), and even academic performance (Krause-Levy et al. 2021).

Empirical studies have shown a high correlation between a sense of belonging and self-efficacy (Lewis et al. 2017) and revealed that high confidence in succeeding with one’s studies strengthens the sense of belonging whereas struggling to understand the subject matter can make the students feel that they do not belong (Rainey et al. 2018). The lack of science identity was noted to weaken the sense of belonging among STEM students whereas a strong science identity strengthened it (Rainey et al. 2018). Women in engineering are suggested to experience weaker belonging due to numerical male dominance which can isolate them from the social group in the workplace, as well as normative male dominance which can hinder fitting in the typically masculine workplace culture (Wilson and VanAntwerp 2021).

Master and Meltzoff’s (2020) STEMO model suggests that the sense of belonging, ability beliefs, and identity contribute to academic outcomes and interest. In the model, identity is connected to linking oneself to a domain (such as engineering) and to a social group (like engineers or engineering students) and valuing that domain or group. Tinto’s (2017) model of persistence in education links the sense of belonging to self-efficacy and perception of curriculum to influence motivation, which then affects the intentions to persist in one’s choice of education. Rainey et al. (2018) discovered that students explained their sense of belonging through personal interest in the course subject and the lack of belonging through explicit lack of interest, yet the lack of personal interest was rarely cited as the reason to leave STEM majors.

Acknowledging the close connections between the concepts of sense of belonging, self-efficacy and ability beliefs, and identity, this study considers belonging in technology to include the facets of the sense of belonging, self-efficacy and ability beliefs, and identification and identity. These conceptual relationships are illustrated in figure 1. In essence, the phenomenon resembles Master and Meltzoff’s (2020) concept of self-representations, which focuses on identification, ability beliefs, and a sense of belonging. However, instead of calling the phenomenon self-representations, which could also refer to other kinds of self-images, this study concentrates on the students’ attachment to technology as a field of study.

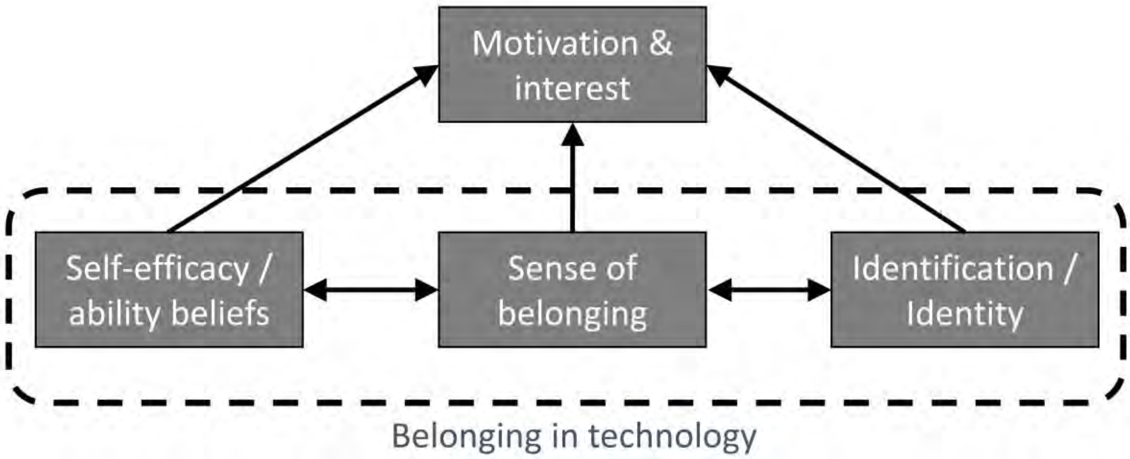

Fig. 1. The conceptual constituents of belonging in technology in the research model for this study

Studies have also indicated the sense of belonging being important factor in students' persistence in engineering (González-Pérez et al. 2022) and in STEM (Lewis et al. 2017; Rainey et al. 2018).

So far, the research findings on female engineering students' sense of belonging seem inconclusive. A literature review by Wilson and VanAntwerp (2021) shows how some studies conclude that female undergraduate students feel they belong in engineering majors, whereas other studies find that they do not, and a third group of studies arrives at mixed results. Belonging appears to be more fragile for graduate students and those undergraduates who did not persist in engineering. However, the belongingness deficit is most evident in studies of racially underrepresented groups, as studies repeatedly show that students of colour report a lower sense of belonging than 'white' engineering students.

It remains also somewhat unclear whether male and female students' sense of belonging in engineering differs. On the class level, some studies indicate that female undergraduate students feel less belonging than male students, some studies report stronger belonging of female students, and some studies found no difference. On the field level studies, female undergraduates report the same or less belonging than males, but on the institutional level, they report the same or more belonging than men. Nevertheless, Wilson and VanAntwerp (2021) suggest that lack of belonging is often among the reasons women leave engineering majors.

Despite a vast body of research on belonging in engineering, little is known about the belonging of non-binary students, and "*the experiences of transgender, gender nonconforming, and nonbinary students are glaringly absent from ongoing discussions of equity and social justice in engineering education*" (Haverkamp 2018, 3). Also, most of the studies on belonging have been conducted in the U.S. and, for example, European or Nordic contexts have scarcely been studied so far. This study aims to fill both of these gaps.

2 METHODOLOGY

2.1 Research question

The main objective of this study was to better understand how gender impacts belonging in technology and engineering in the Finnish context. Another aim was to understand if and how gender as a non-binary variable relates to belonging in engineering/technology. The objectives were pursued by seeking to answer the following research question:

> *Does the sense of belonging of Finnish engineering/technology students differ by gender, related to a) belonging in the field of technology, and b) belonging in the study community?*

2.2 Data

Data was collected by a professional organization for academic engineers in Finland whose members also include students of engineering/technology, computer science, and natural sciences. The data used in this study was derived from the organization's Student Survey which is conducted annually as an online survey, targeting all student members except first-year students. The purpose of the student survey is to collect information on the wellbeing and employment situation of students as well as to gather data on timely, varying topics.

In 2022, the data gathering took place during September 14-30. The invitation to answer the survey was sent to 15 941 students, and altogether 1708 student members participated (response rate 11%). The response rate and the number of respondents were surprisingly low compared to previous years. One explanation may be that during COVID-19 pandemic students were confined to their apartments whereas in 2022 the usual live teaching and events were taking place, thus reducing the interest of the potential participants to respond. Nonetheless, the number of participants was deemed sufficient for statistical analysis and for making inferences about student members in general.

The gender distribution of the population was known, as the information on gender as a binary variable (male/female) based on the Finnish ID could be derived from the organization's membership register. However, the respondents were asked to state their gender in the survey on a 4-point scale (Male/Female/Other/Does not want to disclose). Comparison between the respondent data and the population data showed that the responses were strongly skewed gender-wise, with 55.1% male respondents (72% in the population), 41.3% female respondents (28% in the population), 1.6% other (no information in the population) and 2.0% preferring not the disclose their gender. Therefore, to adjust for the overrepresentation of female respondents and to compensate for the lack of respondents in category other in the original population, gender was weighted as follows: Male 71%, Female 27%, and Other 2%. Those who responded 'does not want to disclose' (n=32) were coded as missing. For this study, we used weighted data and selected engineering/technology/architecture students (n=1488), resulting in the following gender composition: Male 72 %, Female 27 %, Other 1.4 %.

The questions concerning the sense of belonging were adapted from previous studies (e.g., Lewis et al. 2017; Rainey et al. 2018; Wilson and VanAntwerp 2021) and divided into two sub-scales: a. belonging in the field of technology (7 items) and b. belonging in the study community (7 items). A five-point Likert scale (1=strongly disagree to 5=strongly agree) was used for all question items.

2.3 Data analysis

Statistical analyses were done with the statistical software SPSS (version 29). Kruskal-Wallis tests, including pair-wise comparisons, were used to assess differences between the three gender categories of respondents (Male/Female/Other). A significance level of $p<0.05$ was used for all tests. Internal consistency (reliability) of the sub-scales was measured using Cronbach's α and two negatively worded items were reverse coded for this purpose. The correlations between items were examined with Pearson correlation coefficients.

3 RESULTS

The Pearson correlations between individual items in the belonging in the field of technology subscale were according to (Cohen 1988) moderate or strong (between 0.32 and 0.66) as were also most of the correlations between the items in the belonging in the study community subscale (between 0.23 and 0.73). Summated scores revealed a strong correlation ($r = 0.55$) between the sub-scales. However, the correlations between items across the sub-scales were either small (<0.3) or moderate (between 0.3 and 0.5).

3.1 Belonging in the field of technology

The seven items in the sub-scale 'belonging in the field of technology' had a high internal consistency (α=0.858). The results are collected in Table 1. The distribution of the belonging scores were not similar for all groups, as assessed by visual inspection of the boxplots. The differences between gender groups were statistically highly significant (below $p < 0.01$) for all items. However, the effect sizes were small, and none reach even moderate level, remaining below 0.06. We presume the small effect sizes reflect the unequal number of respondents in the three gender categories and recommend conducting confidence interval analyses for the effect sizes in the future to interpret better the differences between the groups.

The results reveal that scores given by male respondents for belonging in technology were the highest for all but one item. The scores given by female respondents were lower than males for six items but higher for "I am proud of studying the field of technology". On the other hand, the scores given by respondents of other gender were the lowest for all items. The largest differences between genders can be discerned for the following items: "People like me can succeed in the field of technology" (Male 4.38; Female 4.09; Other 3.59), "It is important for me to belong in the field of technology" (Male 3.73; Female 3.69; Other 2.94), "Others see me as belonging in the field of technology" (Male 4.13; Female 3.72; Other 3.41) and "I feel like I belong in technology" (Male 4.14; Female 3.80; Other 3.47). Furthermore, persons of other gender have more often considered leaving technology, as the reverse-coded item obtained the lowest score from them.

Table 1. Gender differences regarding Belonging in technology

Question item	Male (mean)	Female (mean)	Other (mean)	Krusk.-Wallis H	p (asympt.)	Effect size
I feel like I belong in the field of technology	4.14	3.80	3.47	51.93	<0.001**	0.034
Others see me as belonging in the field of technology	4.13	3.72	3.41	74.06	<0.001**	0.049
It is important for me to belong in the field of technology	3.73	3.69	2.94	10.74	0.005**	0.006
I will be able to acquire the right skills to succeed in the field of technology	4.25	3.98	3.76	39.80	<0.001**	0.026
People like me can succeed in the field of technology	4.38	4.09	3.59	54.67	<0.001**	0.036
I have often considered changing away from the field of technology [REVERSE CODED]	3.98	3.76	3.53	11.96	0.002**	0.007
I am proud of studying the field of technology	4.22	4.34	3.76	9.65	0.008**	0.005

**highly significant difference

The pairwise comparisons show that with most of the items, there were no statistically significant differences between respondents in categories female and other. However, the items "It is important for me to belong in the field of technology" and "I am proud of studying the field of technology" were rated significantly higher by females than others. The two items are also the only ones that show no statistical difference between the responses of males and females.

3.2 Belonging in the study community

The seven items in the subscale 'belonging in the study community' had a high internal consistency (α=0.855). The results are collected in Table 2. The distribution of the belonging scores were not similar for all groups, as assessed by visual inspection of the boxplots. The differences were statistically highly significant (below $p < 0.01$) for two items. The effect sizes were small and none reach even moderate level. Again, we presume the small effect sizes reflect the unequal number of respondents in the three gender categories.

The results show that gender differences for belonging in the study community were much smaller than those for belonging in the field of technology. Differences between men and women were far less pronounced, as scores given by female respondents slightly exceeded those given by males (for four items) or were on par with them (for two items). The only item where scores given by men and women clearly differed was “I sometimes feel like an outsider in my study community” (reverse coded) which also showed highly significant differences between genders (Male 3.05; Female 2.88; Other 2.35). Another item with highly significant differences was “I can be myself in my study community” (Male 4.07; Female 3.98; Other 3.35).

Table 2. Gender differences regarding Belonging in study community

Question item	Male (mean)	Female (mean)	Other (mean)	Krusk.-Wallis H	p (asympt.)	Effect size
I can be myself in my study community	4.07	3.98	3.35	9.17	0.010**	0.005
I feel I am accepted in my study community	4.03	3.96	3.59	5.70	0.058	0.003
I feel that I am appreciated in my study community	3.70	3.71	3.29	3.34	0.188	0.001
I am excited about my studies	3.56	3.62	3.29	1.98	0.372	0.000
Students support each other and help when necessary	3.93	3.99	3.47	4.68	0.097	0.002
I believe I will graduate from my current studies	4.38	4.43	4.18	1.43	0.489	0.000
I sometimes feel like an outsider in my study community [REVERSE CODED]	3.05	2.88	2.35	9.47	0.009**	0.005

**highly significant difference

The scores given by respondents in the gender category other differed from those given by males and females. Besides the two items mentioned earlier, these respondents less often agreed with the statements “Students support each other and help when necessary”, “I feel I am accepted in my study community”, and “I feel that I am appreciated in my study community”. Yet, the pairwise comparisons showed no statistical differences between the responses of others and males or others and females. This is rather surprising, considering the much lower means of others especially in the items which show statistically significant differences in the simultaneous comparisons of all the three groups. Nonetheless, this could probably be explained by the large deviation in the responses of others from males and females in these particular items.

4 SUMMARY

The results show that students' experiences of both belonging in the field of technology and belonging in the study community differ to some extent by gender also in Finland. However, the gender differences for belonging in the study community (class or institutional level belonging) are much smaller than those for belonging in the field of technology. Although the correlation between these different subscales was strong in the level of summated scores, the correlation of items across the subscales was moderate at the most. This relative independence of the measures of belonging at different levels may provide some degree of explanation of the incongruent findings in prior literature (Wilson and VanAntwerp 2021).

Men are generally strongly convinced that they belong in the field of technology, whereas non-binary respondents feel least often that they belong in the student community. Men's firmer belonging in the field appears to arise from having stronger self-efficacy (ability to acquire the right skills and succeed) and a sense of belonging (feeling of belonging and being seen as belonging) than the other two groups. The importance of academic ability beliefs for men's belonging in engineering has been discovered also by Antonio and Baek (2022). However, the items related to valuing the field of technology (importance to belong and being proud of studying tech) showed no statistical differences between men and women. This aspect was also the only one where women and non-binary respondents differed significantly, with women showing stronger identification with the field of technology.

Although the gender differences for belonging in the study community were smaller than those in the disciplinary level, non-binary respondents more commonly felt like outsiders and not able to be themselves in the community. No statistically significant differences could be detected with respect to feeling accepted, appreciated, or supported in the community (sense of belonging) or being excited or believing in graduation (ability beliefs). Hence, in this subscale, the identity and identification with the community appear to hinder the belonging of others more than self-efficacy or sense of belonging.

Overall, the results suggest that men strongly experience they belong in technology while women express some doubts, especially with respect to their abilities and sense of belonging. Moreover, non-binary respondents are far less certain. In terms of our conceptualisation of belonging in technology and the STEMO model (Master and Meltzoff 2020) high self-efficacy and sense of belonging seem to support especially men's belonging in the field of technology whereas weaker identification with the field as well as the student community decreases the belonging of others. This implies that one key to improving belonging may lie in the broader image of technology, offering more diverse possibilities to identify with.

Probably the biggest limitation of this study is the small number of respondents in the gender category other. In order to reach real gender diversity, equity, and inclusion in engineering education, the views and positions of non-binary gender minorities need to be included in the research on gender and engineering (Haverkamp 2018). Our results show that belonging in technology is not gender equal, and more future research on all gender minorities' belonging in engineering and technology is needed to understand the specific belonging challenges they face.

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COMPARING XR AND DIGITAL FLIPPED METHODS TO MEET LEARNING OBJECTIVES

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ABSTRACT
Digital learning has become increasingly important over the last decade as students and educators adopt new types of technology to keep up with emerging trends. The advent of the Covid-19 pandemic accelerated this rate of change in the higher education sector, leading to remote laboratory experiences and video conferencing becoming increasingly normal. In the wake of this transition, the priority is to understand how these technologies can be blended into existing teaching methodologies, in a complementary way, that enhances the student's pedagogical experience.

The upcoming study will compare three digital-based learning simulations to see which has the most beneficial effect on practical student laboratory experiences. Engineering students will be exposed to one of three forms of digital "pre-lab" laboratory simulation and their academic performance assessed following a physical laboratory. The three forms are a 2D photography "iLabs" simulation, a web-based "low fidelity" simulator and a Unity based immersive Virtual Reality (iVR) lab simulator. All three methods are based on the same empirically derived data. As a control, another group of students will not receive a pre-lab simulation, just a standard pre-lab quiz. The study methods will be tested in a small scale preliminary study with a smaller cohort of students ahead of the main work to optimize the experience.
This research will build upon existing work carried out in the field of virtual labs, that indicates these experiences can help reinforce student learning outcomes, whilst also unpicking the complex relationship between simulation immersion, fidelity and memory recall in a learning context. In addition, the study will give an opportunity to perform a detailed cost versus pedagogical impact assessment, as each of these simulations has been designed and built from the ground up by the authors.

1 INTRODUCTION
Extended Reality or XR is a label commonly used to categorize different types of immersive technologies and concepts. Within this field, there is; Virtual Reality (VR), a technology that creates interactive virtual environments, Augmented Reality (AR), a technology that superimposes virtual information as an overlay on the physical world and Mixed Reality (MR), that combines elements of the previous two within a single display. XR technology has had a resurgence in recent decades due to progress and investment in the associated hardware and software. Alongside commercial and domestic interest, there has been an explosion of interest in XR within Higher Education (HE). In the HE sector, the largest uptake of this technology for research has been in the subject of engineering, with 24% of all papers devoted to it. This research has been applied to many disciplines within the field, including

manufacturing training, workshop health and safety, fluid mechanics, electrical theory and chemical/biological simulation.

1.1 Educational Approaches

One reason XR has been vigorously pursued in HE is the many perceived benefits offered to learning experience, such as "*giving users the freedom to explore knowledge and environments through means not usually afforded to them by traditional method*s" (Logeswaran et al. 2021). However, the assessment of merit in this regard has been slightly undermined due to the lack of studies created with a solid pedagogical framework. In their comprehensive literature review, Radianti et al. (2020) found that surprisingly as few as 32% of studies were associated with a sound pedagogical basis. Instead, most studies considered the technical possibilities first and applied teaching methods retrospectively.

Building on these findings, an increasing number of publications have started to incorporate pedagogical approaches from their inception in a more holistic manner. Most of this work focuses on two main types of pedagogical approach, didactic (i.e. the traditional teacher-centric format given in lecturing) and the "flipped" learner-centric method within a Constructivist framework.

One branch of the latter, Connectivism, has also been suggested for incorporation into XR-based learning due to its aptitude as a collaborative working platform and ability to connect many different types of digital media in a Massive Open Online Course (MOOC) like format. In their recent user-centered interdisciplinary design study, Fromm et al. (2021) looked at how the experiential learning modes (such as concrete experience, reflective observation, abstract conceptualization, and active experimentation) can be designed into a VR experience.

1.2 2D, 3D & Immersion

Following the description in Suh and Prophet (2018), VR can be broken into two subgroups: Non-immersive VR (nVR) - Typically displayed as an image on a computer screen or table/phone device. Immersive VR (iVR) - These systems require users to wear headsets and are linked to an immersive 3D VR environment. A recent examination of iVR's potential for engineering design concluded that it can aid in context-dependent and independent constructivist learning possibly due to the stereoscopic view of objects in an iVR environment, something an nVR experience typically cannot provide (Horvat et al. 2022). However, this finding is not compared to that of a true 2D diagrammatic benchmark and Berthoud and Walsh (2020) also showed his nVR program proved effective at demonstrating 3D complex systems. Both types of VR approaches can allow observation and interaction that is not feasible in real life, for example, the removal of safety guarding or demonstrating physical effects not typically visible to the naked eye. Based on the postulation by Dede (2009), iVR could lead to greater improvements in lateral thinking and knowledge as this technology "*enables them to view a problem either from within the situation (egocentric) or from the outside (exocentric).*" The work by Kisker, Gruber, and Schöne (2021) suggests that iVR could have a greater impact (compared to nVR) due to the experience imprinting on the users' autobiographical memory. The sense of immersion is considered to be the biggest advantage that iVR experiences have compared to transitional teaching methods like 2D videos.

2 METHODOLOGY

2.1 Outstanding Questions

Based on this literature review a number of outstanding research questions have been highlighted: 1) How much of an effect does an iVR experience have on learning outcomes compared to an nVR equivalent? 2) Does a flipped learning experience of a certain digital type aid learning when conducting the actual lab afterwards? 3) Do iVR multilingual interactions have a benefit on learner experiences compared to nVR alternatives? 4) Does a reduction in visual fidelity/detail result in better learning performance? 5) What is the difference in costs between different digital approaches versus pedagogical impact?

2.2 Study Basis

To help address these gaps, a study was created based on a classic practical laboratory experiment; the three-point bending test. In the experiment, beams of different materials and cross-sectional geometry are tested using a Shimadzu EZ-LX Universal Tester machine. Students place the beam on supports, apply a single-point load at the center, and measure the beam deflection at loading intervals. This experiment is taught at scale to approximately 1000 students every year. The opportunity granted by this scale of cohort manifests itself in the ability to collect and analyze laboratory pedagogical data of statistical significance. In addition, the highly structured integration of a Virtual Learning Environment (VLE) based "pre-lab" (or flipped learning) activities, means different digital experiences can be deployed efficiently to students.

2.3 Digital Experiences

In this proposed study, cohorts of students from the 1st year Civil, Mechanical & Bio Engineering will complete a standard pre-laboratory Health and Safety quiz, practical three-point bending lab activity and post lab test. Each group will be differentiated by assigning them a different digital pre-lab, described previously. One of these groups will be acting as a "control" experience with a standard pre-lab quiz, this option will also be default for students who don't opt in to the study as this represents the existing format of the lab activity. To address the question of display/simulation fidelity and the link between reinforcements of learning outcomes/memory recall, three different digital simulations have been created that allow participants to recreate the three-point bending test remotely. This includes 2D, nVR and iVR versions with varying degrees of visual immersion and detail, as this will help decouple the benefits of 2D/3D at the same time. The financial and staff time costs in terms of development have also been considered with each of the different simulations. Assessment in relation to the achievement of learning outcomes is discussed in the following sections.

iLabs 2D Simulation: Stanford University has developed a platform referred to as “iLab”, which allows students to access data from real experiments in an interactive way. During a laboratory experiment, a number of independent variables are set and, for each combination of these, an output state is produced. The iLabs system allows instructors to upload photographic images and numerical data for every possible output state for any particular experiment. Following the upload to the system, students are able to retrieve individual output states by specifying a combination of inputs from an open-access, web-based interface, such as that shown to the left of Fig. 1. While this is a finite number of possible outputs from the experiment, by uploading a large number of possible states the student user can feel in control of making decisions about the settings to be used to execute the experiment.

Web Browser Based “Lo-Fi” Simulation: The authors developed simple, web browser-based simulations. These applications are typically referred to as “lo-fi” due to their simplicity, both in terms of their graphics and numerics. The lo-fi simulations are written using html and javascript. Experimental systems can be constructed using standard elements such as sliders, text boxes and buttons to collect input parameters and output can be displayed as text, numbers or pre-built illustrations of the apparatus. The webpage response can be programmed to replicate the physical system. The objective for this simulation method was to create digital tools that are easy to access, i.e. log-ins or software needed, and can be shared with other educators to reuse or adapt. In addition, there is no further hardware requirement for the construction of the lo-fi simulations, beyond a computer running a text editor and a web browser. In the three-point bending test, shown to the right of Fig. 1, the beam specimen can be selected from a drop-down list, the force applied using a slider and the resultant deflection is displayed. A graphical representation of the extent of deflection is displayed based on a finite number of pre-built digital images. With the standard JavaScript random number generator, each time a result is generated a predetermined amount of experimental error is added to the output.

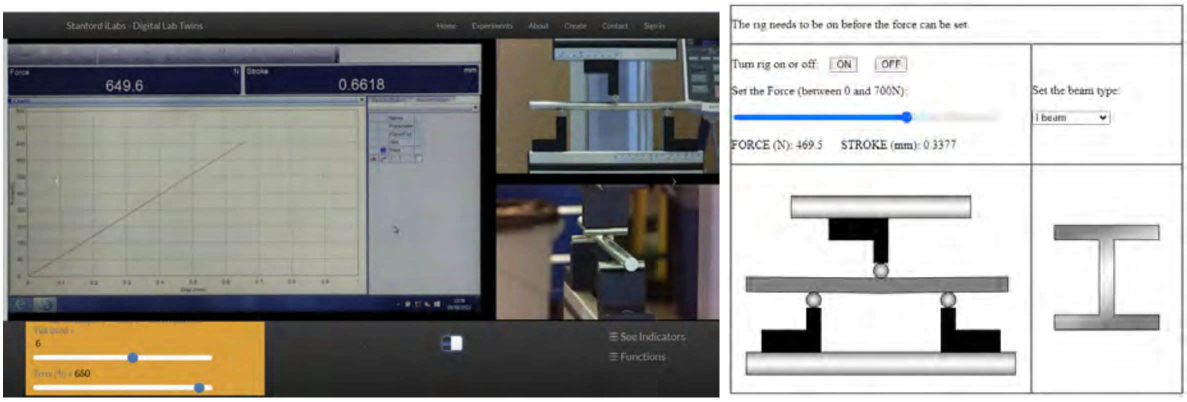

Fig. 1. Typical web browser view of the (Left) iLabs simulation of three-point bending test and (right) "Lo-Fi" html based simulation

Low Fidelity - Unity iVR: To create a fully bespoke iVR experience it was decided that a game engine would be required to provide the truly immersive visual and interactive elements coupled with realistic simulations of physics. The educational version of Unity 3D game engine was selected for use with Meta's Quest 1 & 2 headsets. This software is free for academic use and the basic Quest headsets are low-cost consumer products. The simulation geometry was created using 3D CAD software, processed by the 3D modeling software Blender and imported to the Unity Game Engine. The user experience of the simulation is as follows; once the program is loaded the user is presented with a scale-correct simplified version of the three-point bending apparatus in an empty boundless space (Fig. 2). Using the Oculus controllers or their hands, users can pick up any sample to test and place it in the test machine. It should be noted that this element was considered to be an important differentiator between the simulation types as high levels of interactivity have been previously shown to increase knowledge and skills acquisition (Kyaw et al., 2019). The force applied to the sample can be then adjusted using two large red interactable buttons and the amount of deflection read from the machine's virtual display. The beams will also deform according to the load placed upon them. The deflection is approximated visually, however, the deflection data given is accurate based on empirical data.

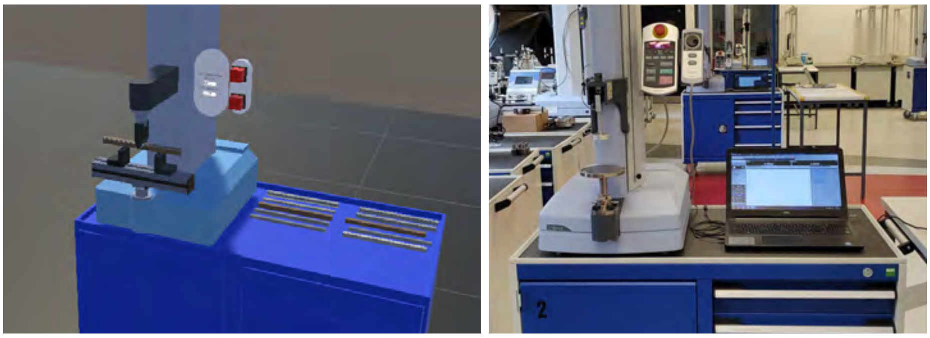

Fig. 2. iVR Unity scene view with Low Fidelity model of the Shimadzu EZ-LX Universal Tester (left), and the real unit (right).

2.4 Simulation Costings

As each of the simulations were built in-house, this presented a unique opportunity to analyze which method represents the best value in terms of education benefit versus financial/time investment. Thus, a detailed assessment accounting for initial costs, staff time for R&D and staff time for activity creation (post R&D) once skills were learnt was created (Table 1, with data based on staff time at ~£25/hr).

Table 1. Cost data for producing each form of digital simulation

Simulation	Total Hours to Create post R&D (hr)	Estimate Staff Costs post R&D	Initial R&D Time to learn skills (hr)	Estimated R&D Staff Costs for learning skills	Items Required to create Simulation	Item Costs Total
iLabs 2D Simulation	12-13	£325	4	£100	Raspberry PI, 3 Cameras lenses, tripods	£600
Web Browser Based “Lo-Fi” Simulation	8	£200	20	£500	Basic PC	£200+
Low Fidelity - Unity iVR	28.5	£712.5	80	£2000	Hi-GPU PC +VR Headset	£1000 + £400

2.5 Methods of assessment

The method of data capture proposed for the main study and utilized here for the preliminary study, falls into two main categories; pedagogical testing (student achievement of learning outcomes), and student’s experiential learning. In the literature, participation experience (or the more qualitative aspects) with less explicit links to the learning outcomes have been covered using self-reported psychological assessment (Feng et al. 2018). This relates to strategies such as the use of questionnaires based on different frameworks. As the preliminary study only includes a small population size, it was decided to approach the sampling from a non-probability (theoretical/grounded theory) basis as the dataset generated would be insufficient for full statistical analysis. To streamline and pseudo-quantise the data collection a combination of NASA's Task Load Index (TLX) methodology, to evaluate user experience, and Likert-framed questions, to help differentiate factors associated with the different digital platforms, was adopted. These strategies have been used successfully in other VR/multimedia comparison studies (Burigat and Chittaro 2016). They will be highly suitable as they can be integrated into the VLE and help compare to a known standard (i.e. the traditional pre-lab) to provide concurrent validity in the analysis. The TLX workload assessment questions are broken down into six subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Frustration and Effort with subscale scores in the range of 1-100. This was implemented in the blackboard VLE, alongside the regular Likert questionnaire with a 7-point scale from "strongly disagree" to "strongly agree". The Likert questions start with data collection related to prior digital media experience and finish with questions relating to measures of usability outside of workload, summarized as Prior experience with computer interfaces, Prior familiarity with VR/XR hardware, Enjoyment, Attention, Effectiveness, Usefulness, Comprehension, Ease of use, Sense of control, Sense of immersion, and Interactivity. A final unbound text box was also included to give optional written feedback. The post-laboratory test is performed by the participants on the VLE. The structure of the test is five diagnostic summative questions, four of which are closed MCQs (a mixture of single and multiple selection types) and one that requires a value within a tolerance range.

2.6 Analysis of findings

Upon completion of the main-study, the survey data will be analyzed and cross referenced for any correlations between the method of pre-lab digital activity and variance in the achievement of learning objectives. Any trends regarding the type of simulation fidelity/interactivity associated with that overall objective will also be considered. This data will then be compared to the overall costs and investments made to create the digital activities via an investment to pedagogical gain ratio.

3 PRELIMINARY STUDY RESULTS and DISCUSSION

Due to low engagement in the preliminary study (5 of 58 participants), only a limited analysis could be performed on the VR pre-lab activity (5 datasets). Within the TLX data, there was variation in how participants perceived the same activity, with each subscale average showing the following (scale 0-100): Mental Demand 31, Physical

Demand 33, Temporal Demand 30, Performance 13, Frustration 21 and Effort 24. This shows that there was generally low frustration and low effort experienced with the task, yet moderate mental demand. These are indicators that the activity was fun and engaging, and that the methodology is reasonable. Interestingly, the largest individual variance was found in 'physical demand' experienced. As the physical strain was small in practice as there was no physical mass to move other than the controller/headset itself, this highlights a possible issue in the framing of the question "*How much physical activity was required*". The likert data showed a favorable experience was had by all participants, with 60% and 54% "Strongly" agreeing that the simulation was easy to use and offering "Excellent" inactivity. Crucially, 39% and 50% of respondents said it was "useful in their understanding of the subject" in the "Strongly Agree" and "Agree" fields respectively. One student commented in the feedback "*Hopefully more labs in the future have VR prelabs to complete vs the standard prelab*", which is very positive. These findings are cautiously considered as provisional, as no post lab data could be collected to examine the educational value of the activity (compared to the baseline), the sample size limited and original comparison premise could not be tested. Aside from the results data, the pilot highlighted several ways that delivery and communication (with students participants) can be improved for the next study. A much larger cohort will be engaged, and a more streamlined version of the survey will also be used to improve the response rates for the main study.

4 SUMMARY and ACKNOWLEDGMENTS

The preliminary study has been effective in highlighting areas that need honing before the main study takes place. Amendments to the delivery of material and communication with student participants will ensure the reliability and validity of the survey data gathered. The final study may incorporate further digital simulations, to determine the effects of increased or decreased fidelity on overall student learning outcomes.

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Soft Skills of Engineering Students

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Keywords*: Soft skills; Interpersonal abilities; Engineering students; Problem-solving*

ABSTRACT

Soft skills are a combination of personal qualities and interpersonal abilities that enable individuals to work effectively with others, communicate clearly, and collectively solve problems. Soft skills are required for effective problem-solving and decision-making. Soft skills, such as communication, teamwork, and empathy, are essential for developing a collaborative culture that encourages high order thinking and building relationships. By developing these soft skills, engineering students can improve their chances of success both in their academic pursuits and in their future careers.

The goal of the study was to evaluate soft skills among engineering students, to provide insight to educators that can help in designing better activities which integrate both skillsets holistically and efficiently. 92 Students were asked to fill out anonymous Likert-like questionnaire about their self-reported soft skills. The findings

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indicate no significant differences between students based on extrinsic factors (gender, campus, department and class), which may lead to both theoretical and educational implications. These findings can be utilized to formulate recommendations for combine soft skills into the engineering curriculum.

1 INTRODUCTION

A successful engineering team must possess a range of abilities that encompasses soft skills. Soft skills include the capacity to engage with others successfully and amicably (Oxford Languages; Itani & Srour 2016). Listening, talking (inside oneself and with others), thinking (critically), and summarizing knowledge are necessary for all types of technical efforts. Due to their importance in engineering practice, numerous researchers have focused on developing this ability individually among engineering students (Sousa & Mouraz 2014). Individuals who possess both soft skills are more likely to achieve success in their personal and professional lives. By developing these abilities, individuals can become more effective problem-solvers, decision-makers, and collaborators, and contribute to the development of more resilient and sustainable systems.

In engineering education, significant attention has been paid to the importance of soft skills among undergraduate and graduate students. In view of the importance of soft skills (Shekh-Abed & Barakat 2022), the research detailed in this paper explored whether engineering students differ in soft skills based on gender, campus, department, and class. The theoretical contribution of this work is a quantitative description of the evaluation of soft skills among engineering students. The practical contribution would be to facilitate the development of instructional activities that promote soft skills for engineering students.

The paper opens with a review on soft skills. This is followed by the study purpose and questions are formulated, and the research methodology is outlined. Then, the findings are presented. Finally, discussion and conclusions are presented.

2 THEORETICAL BACKGROUND

Soft skills cover not only relational skills, but also traits like social responsibility, creativity, ethics, and emotional intelligence (Itani & Srour 2016). Consequently, soft skills include the enhanced ability to communicate and interact with others effectively, the ability to think critically, and the ability to incorporate professionalism in engineering practice (Barakat 2015). Organizations strongly emphasize interpersonal skills (e.g., creating rapport) and communication skills (e.g., customizing your message to the appropriate audience). Several institutions, such as the NAE (National Academy of Engineering) and the ABET (Accreditation Council for Engineering and Technology), have increasingly underlined the significance of soft skills in engineering. This has resulted in multiple contribution enriching the literature of soft skills integration in the curriculum (Barakat and Plouff 2014).

According to a study conducted by the Monarch Institute, 85 percent of the abilities required for employability are soft skills, whereas 15 percent are technical skills. This emphasizes the need for teaching soft skills in the classroom. Studies have demonstrated that engineers must be capable of adapting to new information and independently, critically, and proactively express their thoughts. As team members, engineers must develop intrapersonal and self-management abilities that enable them to regulate impulsive inclinations, follow through on promises, accept responsibility, and handle stress. In addition, research has shown that engineering

students must be able to work in teams, manage interdisciplinary groups, and comprehend society in order to discover new solutions to real-world problems. Students must evaluate the environmental, ethical, and political consequences of their acts (de Campos et al. 2020; Klafke 2005).
Caten and his colleagues argue that soft skills are more important than technical abilities for present and future engineers (ten Caten et al. 2019). There are numerous instances of non-technical abilities that make professionals more capable of taking charge of their careers and responding to market needs. These abilities include leadership, innovation, communication, management, ethics, agility, resiliency, and adaptability. The necessary skills for post-university management and leadership positions are those that develop based on humanities and social sciences, such as: demonstrating passion and interest, accepting current roles and responsibilities while seeking continuous improvement; gaining experience in other projects and working groups, understanding and resolving organizational challenges; and self-assessment to learn from mistakes, cultivating values that promote trust (Compton 2008).
Studies (Awuor et al. 2022; Shekh-Abed et al. 2021; Gero et al. 2022) note that through teamwork and project-based learning, students improve their knowledge in the technical, behavioral, and contextual competence areas of project management. Awuor et al. (2022) reveal that students' competences in creativity, leadership, and negotiation have been significantly enhanced thanks to teamwork. Given the focus of the research, the report includes a lengthy self-evaluation questionnaire about employability abilities. In order to teach students to be proactive problem solvers and critical thinkers, the authors recommend that institutions and teachers reevaluate how they already include transferable skills into the curriculum (Ojiako et al. 2011). Aranzabal et al. (2022) present a way to construct a well-rounded project team as a means to enhance students' performance in project-based learning. In order to get students thinking about the value of teamwork, the authors use Belbin's role theory and find that groups assigned to one of nine roles outperform those assigned by the students themselves. According to Belbin's role theory from 2010, a team member's role is "a tendency to behave, contribute, and interrelate with others in a particular way," with these characteristics being shaped by factors such as one's own personality, cognitive abilities, current values and motivation, field constraints or external working environment, one's own experience and culture, and role learning. Researchers found that when students were exposed to role theory, they improved their abilities to operate in a roles- and skills-based setting, as well as their cooperative learning, interpersonal interactions, and social skills (Aranzabal et al. 2022).

3 RESEARCH PURPOSE AND QUESTIONS

The purpose of the study was to investigate the effect of different extrinsic factors representing demographics (gender), socio-economic status (campus location), technical discipline (engineering program), and educational career stage (class), on the perception and application of soft skills among engineering students. Ultimately, the goal was to provide educators with information that will assist them in planning and instructional design of more effective activities combining soft skills holistically and systematically. The following questions were derived from the research goal:

- Do soft skills perception and application differ among engineering students based on the following factors, and to what extent:

1. Gender (representing demographics)?

2. Campus geographical location (representing socio-economic status)?
3. Engineering program (representing technical discipline)?
4. Class (representing educational career stage)?

4 METHODOLOGY

4.1 Participants

A questionnaire was sent out to all engineering students at The University of Texas at Tyler (UT-Tyler) inquiring about students' perception and application of soft skills. The total number of students who responded to the questionnaire was 92 engineering students. This includes 58 (63%) students from Tyler Main Campus (TYL) and 34 (37%) students from Houston Enginieering Center Campus (HEC). Demographics of the participating students are presented in Table 1. The ratio between male and female students was 2.2 (69% male and 31% female) in both campuses, which is higher than U.S. national average of gender ratio in engineering programs and closer to the international averages of the same ratio. Geographically, TYL Campus is located in a relatively small rural city, while HEC Campus is located in the middle of Houston, which is an enormous major city (inner-City) with a high concentration of less affluent and minority students. Educational career stage included students ranging from Freshman to Seniors, as well as students in the Masters program. Technical disciplines included four engineering disciplines: Civil, Electrical, Mechanical, and Construction Management. It is to be noted that the majority of graduate students who answered the survey are international with a diverse background of engineering education and the accreditation system their universities could have been following.

Table 1. Demographics of participating students responding to questionnaire

Demographic	Students
White	39
Hispanic	19
African American	8
American Indian or Native Hawaiian	4
Other	22
Male	60
Female	27
Prefer not to say/Non-binary	5
Total	92

4.2 Procedure

Quantitative method was utilized in this study. An anonymous questionnaire was offered for all engineering students at UT-Tyler in the form of a Qualtrics® questionnaire. Students were invited to voluntarily fill the questionnaire within a week period at the beginning of the spring semester of 2022. Ninety-two engineering students ($N = 92$) completed this self-reporting questionnaire. The Kolmogorov–Smirnov test of normality (goodness of fit) showed that a normal distribution can be assumed for all variables ($p > 0.05$). Therefore, independent samples t-test and one-way ANOVA test were conducted.

4.3 Instruments

The self-report questionnaire which was composed specifically for this research comprised of 25 statements based on the characteristics of soft skills (Kantrowitz 2005) of engineers. The answers to the questionnaire were based on a five-level Likert scale, ranging between “highly agree” and “highly disagree”, refering to soft skills. The questionnaire was validated by two experts in engineering education. The internal consistency, or coefficient of reliability of the soft skills statements (Cronbach’s α =0.879) were found to be acceptable. Thus, for example, the statement “as a student in an engineering project team, I have confidence in my work and abilities in performing tasks in experiments / project” indicates relatively high soft skills Samples from the soft skills questionnaire are provided in Table 2.

Table 2. Self-reporting questionnaire: soft skills (sample statements)

Statement	Soft Skills
As a student in an engineering project team, I have confidence in my work and abilities in performing tasks in experiments / project	High
As a student in an engineering project team, I collaborate with others to accomplish the task	High
As a student in an engineering project team, I tend not to ask questions or get help from others	Low
As a student in an engineering project team, after making a decision, I often rethink my decision and change my mind	Low

5 RESULTS

Students’ answers were grouped from the questionnaire allowing calculation of the mean score *M* (ranging between 0 and 5) and the standard deviation *SD* for each group of students. The first grouping attempt was by splitting male and female into two separate groups and comparing their results in soft skills. As shown by Table 3, the descriptive statistics (*M*, *SD*) were calculated by gender. According to a t-test (equal variances), there is no significant difference between male and female students in soft skills $t(85) = 0.207$, $p > 0.05$. Both groups (males and females) have the same ability of soft skills.

Table 3. Descriptive statistics for students’ answers grouped by gender

Gender	N	Soft Skills	
		M	*SD*
Male	62	4.04	0.48
Female	27	4.09	0.54

The second grouping attempt was by splitting answers based on socio-economic status. This was achieved by grouping responses based on the campus they came from which is either TYL or HEC. As was mentioned, TYL is located in a relatively small rural city with an almost homogeneous population socially and economically. HEC is located in the inner-city part of the enormous city of Houston where the majority of the population is diverse in ethnicity with income around the national poverty level. Comparing results from these groups regarding soft skills as shown by Table 4, the descriptive statistics (*M*, *SD*) were calculated by campus. According to a t-test (equal variances), there is no significant difference between TYL and HEC in soft skills t(90) = -0.086, p >0.05. Therefore, students in both campuses have the same perception and application experiences of soft skills.

Table 4. Descriptive statistics for students' answers grouped by campus

Campus	N	Soft Skills	
		M	SD
TYL CAMPUS	58	4.00	0.49
HEC CAMPUS	34	4.15	0.47

The third grouping attempt was by splitting answers based on technical disciplines represented by the home departments of students. This produced four separate groups. Descriptive statistics of the four groups are shown in Table 5, the descriptive statistics (*M*, *SD*) were calculated by departments. According to a one-way ANOVA test (equal variances), there is no significant difference in soft skills F(3, 88) = 0. 861, p > 0.05, between the engineering departments. Students in different engineering departments have similar abilities, perceptions, and experiences regarding soft skills.

Table 5. Descriptive statistics for stud ents' answers grouped by department

Department	N	Soft Skills	
		M	SD
Mechanical Engineering	62	4.11	0.47
Electrical Engineering	13	3.91	0.54
Civil Engineering	11	3.92	0.60
Construction Management	6	4.08	0.38

The fourth grouping attempt was by splitting classes (studying year) into five separate groups of students (Freshman, Sophomore, Junior, Senior, and Graduates) and comparing their results in soft skills. As shown by Table 6, the descriptive statistics (*M*, *SD*) were calculated by class in terms. According to a one-way ANOVA test (equal variances), there is no significant difference in soft skills F(4, 87) = 1.591, p > 0.05, between the engineering classes in terms. Students in different engineering disciplines have similar abilities and perceptions of soft skills.

Table 6. Descriptive statistics for students' answers grouped by class

Class	N	Soft Skills	
		M	SD
Freshman	9	3.80	0.69
Sophomore	4	3.87	0.19
Junior	18	4.22	0.46
Senior	40	4.11	0.46
Graduates	21	3.95	0.47

6 SUMMARY

Soft skills such as active listening, empathy, and collaboration are necessary for establishing trust and fostering relationships with others. Individuals are more likely to be able to identify and address systemic problems and work towards sustainable solutions if they are able to work effectively with others and establish strong relationships.

Results collected and presented in the results' section show that soft skills perception by students has no significant differences based on extrinsic factors such as gender and socio-economic level. In fact, results show that there are no significant differences in soft skills perception by students based on gender, campus (Geographical location), department (Career), and class (stage in the career or year of study). This suggests that current methods and techniques to build and improve soft skills are effective and that all students may benefit from expanded dedicated activities to improve soft skills.

Since there are no significant differences among the different groups, it may be worthwhile to develop activities that are universally applicable to all students which expand from current proven methods for soft skills development. This could involve workshops, seminars, or other training sessions focused on developing soft skills. In addition, it may be helpful to integrate these skills into the curriculum in a more deliberate and intentional manner. This could involve incorporating activities and assignments that specifically target the development of soft skills. Combining reflection assignments and project-based learning into engineering courses (Shekh-Abed & Stav 2023) could enhance both hard and soft skills.

Overall, the findings suggest that there is a need for dedicated activities to improve soft skills for all students, regardless of gender, campus, department, or class. By addressing these skill sets in a more intentional and deliberate way, students may be better equipped to succeed in their academic and professional pursuits.

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THE ROLE OF EARTH SYSTEM LITERACY IN SUSTAINABILITY EDUCATION FOR ENGINEERS

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Conference Key Areas: *Addressing the challenges of Climate Change and Sustainability; Embedding Sustainabiliy and Ethics in the Curriculum*

Keywords: *Sustainability competencies, Earth system literacy, Engineering skills*

ABSTRACT

Engineers should be able to demonstrate sustainability competencies transcending their specialised discipline. But all cross-disciplinary sustainability competencies are not targeted adequately in engineering education and are often mismatched with competencies required by engineers in their professional roles. Future engineers should have an understanding of the environment alongside technical knowledge, with all engineering design and product showing consideration to sustainability. The study of the Earth system is relevant to the understanding of environmental issues and the interplay between the sub-systems of the Earth (atmosphere, geosphere, biosphere and hydrosphere) . Yet, integration of Earth system literacy in the engineering curriculum has received minimal attention. This paper discusses the sustainability competencies in engineering education and, investigates if they can be addressed through Earth system literacy where weak or lacking. Based on two geology courses delivered to engineering students focusing on the sustainable management of different Earth resources with an understanding of their formation and extraction, it is evident that Earth system literacy can strengthen system thinking and, strategic and normative competencies in engineers. Most importantly it can target anticipatory competency that is not addressed adequately in conventional engineering courses.

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1 INTRODUCTION

Sustainable competency skills for engineers are very important in their professional lives for problem solving and bringing in engineering solutions relevant to the twenty-first century. The knowledge, skills, values and attitudes of engineers should transcend their specialised engineering discipline, with a shift in attitude from applying known solutions to well-defined problems for system optimisation, to facilitating system change by addressing complex cross-disciplinary challenges with no obvious solutions (Leifler and Dahlin 2020). It is crucial that engineers find sustainable solutions with due attention to global challenges such as climate change, pollution and loss of biodiversity, often triggered by excessive consumption of natural resources and the discharge of chemicals into the environment. This can occur at ant stage of a product development, from its discovery and design to the disposal of products at the end of its life cycle.

Sustainability education should be leading curriculum development and integrated to it, encompassing interdisciplinary, social and ethical knowledges. Although this has received considerable attention recently, engineering education is primarily focused on technical knowledge (Crofton 2000). Also, there is a mismatch between the sustainable competencies that engineering graduates possess and those required by industry. Besides, both qualitative and quantitative aspects of engineering sustainability are generally introduced to students through stand-alone modules, without being embedded in the curriculum design to complement the technical knowledge. In this study, we looked at the feasibility of Earth system literacy bridging some of these existing gaps in engineering sustainability education.

2 EARTH SYSTEM LITERACY FOR SUSTAINABILITY EDUCATION IN ENGINEERING

The Earth is a complex, open dynamic system with continuous interactions through cycling of matter and flow of energy between its interrelated sub-systems (atmosphere, geosphere, biosphere and hydrosphere). Although the Earth is continuously evolving, Earth processes (erosion, evolution, plate tectonics) are unchanging, driven by physical and chemical principles (Ladue et al. 2010). However, the rates of such processes might change both naturally and due to impacts from human activities which can result in rapid changes through Earth systems. The focus of Earth system literacy should be to foster understanding of the fundamental concepts of Earth systems to enable making informed and responsible decisions regarding Earth and its resources, to address the global challenges of changing climate, water shortage and depletion of natural resources. As human behaviour continues to threaten the sustainability of the Earth subsystems, the feedback mechanism of the Earth system might allow the subsystems to bounce back to balance. However, in this process, there can be considerable changes to all the spheres that will be damaging for human beings (Boyce et al. 2023). It would be very important to understand the realistic role of humans on Earth towards this.

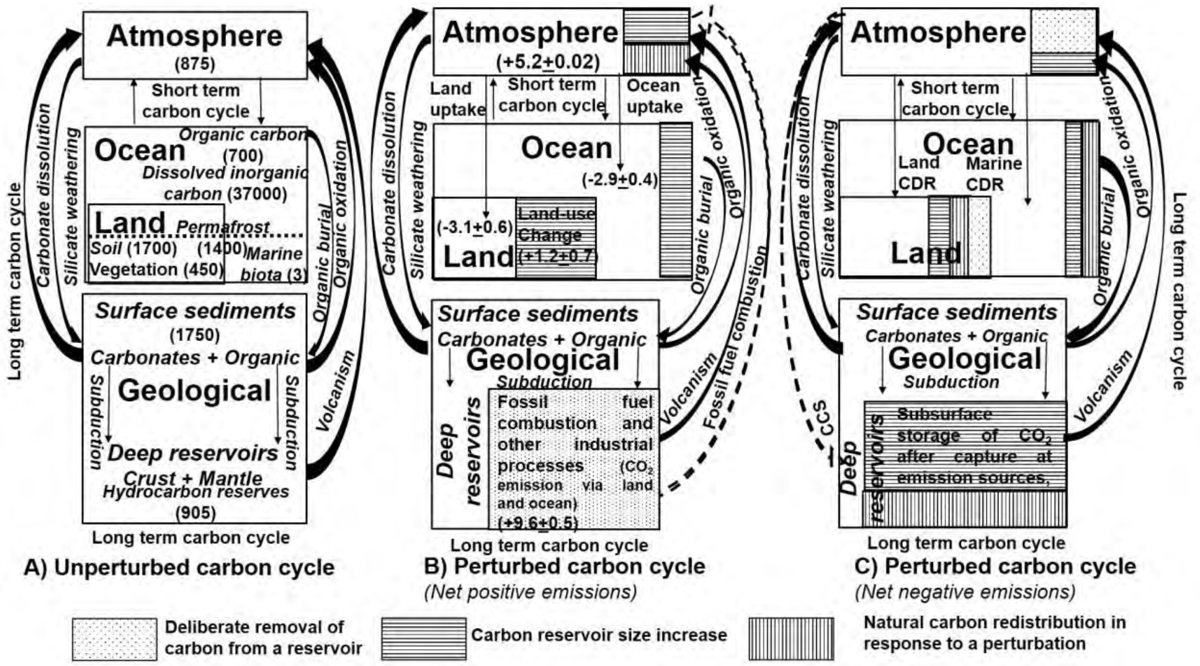

Fig. 1. The natural carbon cycle term cycles A) Unperturbed, with the carbon in stock in the main reservoirs indicated in GtC (gigatonnes of carbon) in parentheses B) Perturbed by anthropogenic activities with carbon fluxes in GtC/year averaged for the decade 2012-2021 indicated in parentheses. C) Perturbed by CO_2 removal (CDR) by enhancement of CO_2 sinks through processes such as afforestation and carbon capture and storage (CCS). Modified after Keller et al. 2018; Friedlingstein et al. 2022; Boyce et al. 2022.

Earth system literacy is the interdisciplinary study of Earth's geology with aspects of biology, physics, chemistry and mathematics. It would be important for engineers to address the influence of human intervention on the functioning and interaction of the Earth systems to prevent any disruption. To reduce CO_2 emissions some direct actions for engineers would be, to consider resilience in the infrastructure they design and build, to improve energy efficiency in any good they manufacture from refrigerators to automobiles, replace carbon fuels with renewables in the manufacturing steps, and facilitate CO_2 sequestering by capturing and storing the CO_2 at the point of emission. For sustainability consideration, these approaches should be based on an understanding of environmental issues, climate change and resource depletion and the interconnected nature of these challenges, grounded on Earth system literacy. As an example, the carbon cycle consists of both short (large fluxes between relatively small reservoirs functioning at decadal scales) and long (small fluxes between enormous reservoirs accrued over thousands to millions of years) cycles, (Fig. 1A). The CO_2 is bound or converted by the ocean and terrestrial sinks and removed from the atmosphere naturally, driven by different geological processes (Table 1). However, this natural cycle can be perturbed by anthropogenic activities, leading to negative net CO_2 emissions by removal through different processes (Table 1) and positive net CO_2 emissions by combustion of fossil fuels and cement production (Fig. 1B and C). As one of the six habits of engineering defined by the National Academy of Engineering, it would be important for engineers to consider the impact of engineering on environment. The should be able to recognise any anthropogenic impact and its perturbation to a natural cycle in the context of not just the operational carbon footprint for a designed product but the embodied carbon footprint during its life cycle. Another example is the production of traction lithium-ion batteries for automobiles, where the impact of mineral resources need to be considered in the life cycle assessment. Any land disturbance due to mining activities, release of mine tailings and unused resource extraction such as copper (Kosai et al. 2021), needs an understanding of basic Earth system concepts taking into account the geological occurrences of these resources.

Table 1. Geological processes pertaining to carbon cycle and human perturbation to remove carbon dioxide from the atmosphere

Geological processes	Description (as relevant to the carbon cycle)
Carbonate dissolution	The breakdown of a carbonate rich rock (e.g. limestone) in contact with acidic water to soluable bicarbonate and CO_2.
Silicate weathering	When calcium and magnesium bearing silicate rocks break down during weathering, it produces alkalinity that can neutralise CO_2 emissions by driving the precipitation of carbonate minerals.
Subduction	When two tectonic plates converge at a plate boundary, the denser plate is driven beneath the other, transporting carbon to the Earth’s interior as organic carbon and carbonates.
Organic burial	Organic carbon buried in marine sediment over millions of years serving as a net sink for atmospheric CO_2
Organic oxidation	The oxidation of organic carbon from sedimentary rocks releases CO_2 over geological timescales from long term storage.
Carbon dioxide removal processes	
Land-based	Afforestation, reforestation, carbon farming, wetland restoration
Marine based	Abiotic approaches based on the properties of the ocean (e.g. alkalinity enhancement) and biotic approaches based on photosynthetic organisms in the sea (e.g. seaweed cultivation).
Enhanced weathering	An enhancement of the natural weathering of rocks to trap CO_2 by spreading large quantities of selected, finely ground silicate rocks such as basalt on extensive land area and sea surfaces.
BECC	Bioenergy with carbon capture and storage is a process which extracts bioenergy from biomass followed by the capture and storage of the CO_2 produced during the conversion.

3 OBJECTIVES OF THE STUDY

The main objective of this study is, to assess if embedding Earth system literacy in the engineering curriculum can benefit the sustainability education of engineers, beyond the scope of conventional engineering courses. The study will First assess any gap in sustainability competencies of engineers related to only engineering skills. It will then identify the specific sustainability competences that can be developed by introducing engineering students to basic concepts on Earth systems.

4 METHODOLOGY

Sustainability competencies integrated to engineering skills are initially assessed through literature review to identify the gaps in sustainability competencies in engineering education. Two sustainability focused geology courses delivered successfully to engineering students in a London University over the last seven years in a MSc programme on natural resource are then considered to identify relevant Earth system topics for this study. The two courses focus on the extraction of Earth resources and their return of waste and pollutants to the environment, with appropriate methods adopted to deliver geology contents to engineering students (Basu 2022). The topics covered in these courses and the learning outcomes are correlated to engineering sustainability competencies to identify if any gap in the sustainability competency skills in engineering education can be addressed through Earth system literacy.

5 RESULTS AND DISCUSSION

5.1 The relevance of Earth system literacy to Engineering sustainability education

Sustainability education for engineers have focused on engineering specific skills and related cross-disciplinary competencies summarised below (Perpignan et al. 2020; Quelhas et al. 2019):

Knowledge and understanding to develop systemic and critical thinking to enable solving a complex problem, with an understanding of the environment.

Engineering analyses to enable systemic thinking and collaborative working in order to solve a complex problem, enabling engineers to identify interactions between systems and people, integrating sustainability into their performance.

Engineering design to enable solving a complex problem with consideration to sustainability, taking into account environmental, social and economic factors.

Investigations to enable critical thinking to solve a problem and, develop normative competence and self-knowledge, with an ability to recognise professional responsibilities in forwarding sustainability goals and objectives.

Engineering practice that enables critical thinking to solve a complex problem with abilities of lateral, logical and critical thinking, based on normative and strategic competencies.

Making judgements to enable critical thinking and develop strategic competence to contribute to collective action within an organisation, implementing innovative actions and rethinking of company strategies.

Communication and team working to enable collaborative working and the ability of transdisciplinary thinking.

Lifelong learning focusing on self-knowledge to reflect on the individual role in the society to advocate sustainability values and goals.

Clearly, all cross-disciplinary skills needed for sustainability education are not targeted in trainings focused on just engineering skills. While critical thinking and solving a complex problem are targeted strongly, collaboration, systemic thinking, normative competence, self knowledge and strategic competence are weakly addressed (Perpignan et al. 2020). Particularly, anticipatory competency is not addressed at all, with a lack of knowledge and abilities that enables contextualization of engineering solutions in a broader context (Perpignan et al. 2020; Quelhas et al. 2019). Also, there is a mismatch in the sustainability competencies engineering graduates possess and that required in their professional roles (Yu et al. 2022). It becomes important for higher education to consider how to better support engineering graduates to build their sustainability competencies for the work place.The eight generic sustainability competencies of relevance to skilled engineers in their professional roles are, leadership, design, professionalism, lifelong learning, technical theory, communication, problem solving and teamwork (Yu et al. 2022). There is an emphasis on interdisciplinary skills for teamwork, understanding and applying knowledge of natural sciences related to the dimension of technical theory and designing a system or process taking into account environmental constraints. Earth system literacy has the potential to develop interdisciplinary skills for engineers to enable effective collaboration with environmental insights. Based on two geological courses offered to engineering students, the contributions of Earth system literacy towards their sustainability competencies are summarised below (Table 2).

Table 2. Sustainability competency skills for engineers built on Earth system literacy

Topic	Key learning objective and UN sustainable development goals (SDGs)	Intended learning outcome(s)	Relevant Engineering sustainability competencies
Geology for Sustainable Resource Management and Energy Transition			
Rocks and minerals	Understand the importance of geological materials as resources. *Addresses UN SDG 13.*	Identify a range of rocks and minerals, relating their properties and uses. Decouple the natural decay of Earth materials, from impacts of anthropogenic activities.	Anticipatory and deeper system thinking related to gradual and catastrophic processes and impacts on natural resources.
Plate tectonics	Describe the interactions between the Earth sub-systems, within the dimension of deep time and spatial scale of geologic processes. *Addresses UN SDG 13.*	Understand the origin and alteration of rocks related to Earth processes. Locate natural resources for extraction. Provide an integrated view on how the Earth functions as a system, with interacting sub-systems.	Deep system thinking on how Earth functioned in the past to forecast how conditions might change in the future.
Subsurface energy deposits	Enable identification of hydrocarbon bearing geological structures for exploitation, recognising associated risks. *Addresses UN SDGs 6, 7, 13.*	Apply geological concepts to understand the processes of hydrocarbon formation and entrapment. Critically relate hydrocarbon extraction to any associated environmental issues.	Anticipatory, with an understanding of Earth system processes in time and space, across scales of many orders of magnitude.

Underground storage of CO_2 and H_2	Consider emerging CO_2/ H_2 subsurface storage technologies to tackle climate change. *Addresses UN SDGs 6, 7, 13, 15.*	Characterise the subsurface to assess the opportunities for CO_2 and H_2 storage. Address key issues around CO_2/ H_2 subsurface storage, related to fluid flow and trapping mechanisms.	System and critical thinking with a holistic understanding of the extraction of natural resources, mitigating environmental impacts.
Earth Resources and sustainability			
Mining and mining life cycle	Critically consider the protection of the environment during exploitation of mineral resources. *Addresses UN SDGs 6,13,15.*	Describe the different stages of mining for mineral extraction, considering the embedded energy and environmental footprint, during the life cycle of a mineral deposit.	System and critical thinking with a holistic understanding of the extraction of natural resources.
Types of ore deposits (e.g. magmatic, hydrothermal, surface)	Critcally consider the sustainable extraction of minerals from ore deposits. *Addresses UN SDGs 6,13, 15.*	Characterise ore deposits based on their formation. Identify potential environmental issues associated with extraction of mineral resources.	Anticipatory and system thinking, with an understanding of Earth system processes in deep time and space.
Critical metals and byproducts for green technology	Develop an understanding on the viability of sustainable extraction of critical metals from their ore deposits *Addresses UN SDGs 6, 7, 13.*	Identify ore deposits bearing critical elements for energy transition. Appraise the factors controlling the demand and supply of critical metals. Consider the availability of mineral resources and the importance of their recycling.	Strategic competence, with an integrated understanding of the technological and economic impacts of resource extraction.
Seafloor mining	Critically consider the environmental impacts during the process of deep sea mining, and the research gaps in this field. *Addresses UN SDGs 13, 15.*	Give an overview of seafloor mineralisation. Identify the technological and geologic challenges associated with exploration of deep sea minerals in the context of ore type and water depth.	Strategic competence, with an integrated understanding of the technological, economic and social impacts of resource extraction.

Environmental, social and governance issues in mining	Gain an overview of best practices and regulations for the mining sector, considering the social and environmental impacts of mining. *Addresses UN SDGs 6, 13, 16.*	Evaluate environmental and societal aspects of Earth's mineral resources. Identify best practices related to opening, operating and closing a mine.	Normative and strategic competence with a holistic understanding of environmental, economic and social aspects of sustainability.

5.2 Earth system literacy in engineering education: Challenges and opportunities

The learning outcomes from Earth system literacy courses focus on Earth processes at different temporal and spatial scales, that influence the availability and sustainability of Earth resources (Table 2). The learning outcomes from engineering courses focus on the development and design of products, processes and systems with emphasis on the technical aspects of material choice and energy consumption (Perpignan et al. 2020). The effective integration of Earth system literacy in engineering education to reflect on the learning outcomes, will require time and effort with collaboration between geoscience and engineering educators, proficient in their respective field, but receptive to the expertise of others. Earth system literacy is an ongoing process, so specific actions need to be identified to enable engineering students to gradually acquire knowledge and understanding in this area integrated to their curriculum. In this context, embedding Earth system concepts in existing engineering programmes without relying on stand-alone Earth system courses designed for engineering students would be a major challenge. This can be trialled in a selected engineering programme within its existing structure, with key outputs aligned to its core learning outcomes. A suitable programme would be one with emphasis on sustainability education, with opportunities to flexibly incorporate innovative methods of teaching. It would be very important to consider the pedagogic approaches for such implementation, noting that creating contents and designing an integrated framework for such a purpose will be challenged by students' diverse learning experiences and goals depending on their specific engineering field.

6 SUMMARY

Crossdisciplinary sustanainibility competencies including strategic, normative, anticipatory, and deeper system thinking, can be strengthened and developed in engineering education by embedding Earth system literacy in the curriculum. Basic Earth system concepts related to the formation and occurrence of different natural resources can be introduced in engineering education to expand students' understanding of sustainability with environmental insights. However, it would be challenging to embed Earth system literacy in existing engineering programmes integrated to the curriculum, moving away from stand-alone Earth system courses for engineers.

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EXPLORING THE VARIATION IN GENDER BALANCE ON UNDERGRADUATE ENGINEERING COURSES IN UK UNIVERSITIES

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Conference Key Areas*: Equality, Diversity and Inclusion in Engineering Education, Recruitment and Retention of Engineering Students*
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ABSTRACT

The underrepresentation of women in engineering remains a persistent issue despite efforts to attract more female students. The percentage of UK engineering undergraduates who are female is published annually, however no institutional breakdown is given. This scoping study aims to inform the direction of future research by investigating the nature and possible causes of the distribution of female engineering undergraduates across the UK HE-sector. Student data gathered from UK universities by the Higher Education Statistics Agency (HESA) for 2019/20 is explored using Tableau. Overall, 16% of UK engineering undergraduates are female but this varies from 5% to 36% for individual universities, with more prestigious institutions generally having a higher percentage. The findings suggest some association between gender balance and the level of qualifications prior to university: in general, the higher the academic achievement on entry to a university the better the gender balance at that institution while the percentage of women appears to be independent of the number of engineering undergraduates at a university. The HESA data also confirm that certain disciplines attract more women and consequently the subject areas offered by a university can influence its gender balance in undergraduate engineering. The literature offers several possible explanations for these findings, but further study is needed to investigate the differences in female representation at a more granular level, acknowledging the agency and individuality of both the universities and the students.

1 INTRODUCTION

1.1 Underrepresentation of women in engineering

Underrepresentation of women in engineering remains a persistent issue in the UK despite substantial efforts to attract more female students. Around 18% of students studying for a degree in engineering and technology are female compared to 57% for all degree subjects (Engineering UK 2020). The percentage of UK engineering undergraduates who are female is published annually, however no breakdown is given by Higher Education institution (HEI). A review of literature shows substantial research into *why* women may or may not choose to study STEM subjects or, more specifically, engineering, while further research is recommended into *where* they are studying (Ro, Fernandez and Alcott 2021). A more even distribution of female engineering undergraduates across the HE-sector will not increase the overall numbers, however a scoping study to understand the current distribution can inform future research e.g. do some universities actively attract women who might not otherwise have considered engineering while some HEIs are so discouraging that the potential female students choose non-engineering options?

There is a link between increased socio-economic status (SES) of the family and the likelihood of enrolment at more prestigious universities (Carpentier 2021), but the literature is inconsistent regarding gender balance in STEM and the status of a UK university. Codiroli McMaster (2017) suggests the likelihood of young women choosing STEM (Science, Technology, Engineering and Mathematics) over other high-return subjects increases with increased family SES whereas Ro, Fernandez and Alcott (2021) found a lower level of women's participation in STEM subjects at prestigious universities.

The research questions guiding this study are:

RQ1: How are female engineering undergraduates distributed across UK universities, by university type and discipline?

RQ2: Are there characteristics shared by universities with equivalent percentages of female engineering undergraduates?

1.2 Undergraduate engineering at UK universities

In the UK, students apply for undergraduate courses through a central university and college admissions service (UCAS) by selecting up to five combinations of university and programme of study. A university specifies its academic entry requirements for each of its programmes as either A-level (or equivalent) subjects and grades, or a more generalised 'UCAS tariff', consequently students' application options are limited by their academic qualifications. It is worth noting that a student is normally expected to stay at the same institution throughout their degree course and it is also less straightforward to change 'major' than in other HE systems – in fact the concept of a 'major' is less relevant in the UK as engineering is frequently the only subject studied on the programme (ie without humanities or social science modules as in the US). Consequently, an application to study engineering and a university's offer of a place are major commitments on both sides and carry an element of risk, especially if the student has not been exposed to engineering at school.

The UK HE-sector became nominally unitary when a binary divide between universities and polytechnics was abolished in 1992. However, it is widely acknowledged that hierarchies exist, often subdivided into Russell Group (a self-selective elite group), the remaining 'pre-92' HEIs, and those established 'post-92'. These categories are often assumed to align with institutional differentiation by prestige, resource and mission e.g research or teaching focus, academic or vocational priority, and international, national or local outlook (Carpentier 2021). Annual tuition fees for all UK undergraduate engineering courses are the same and are usually covered by a loan through the national student finance scheme (although Scots attending Scottish universities are currently fully funded). However, the cost of living in different locations may influence a student's choice of university.

2 METHODOLOGY

This baseline study analyses data on all UK undergraduates studying engineering in the academic year 2019/20 - the most recent year unaffected by COVID19 - at the 73 HE providers with the largest cohorts which together cover 95% of the undergraduate engineering studied in the UK (excluding the Open University which only offers distance learning) according to submissions to the Higher Education Statistics Agency (HESA). The dataset, which includes 22 Russell Group (RG) universities, 20 non-RG from pre-92 and 31 post-92 establishments, includes student gender and domicile along with the branch of engineering studied, rounded for anonymity and provided as Full Person Equivalent (FPE) (HESA 2023). The visual analytics software Tableau is used to explore this large dataset. It is noted that additional data gathered from university websites was collected in 2022 and this information may have changed since the students applied for their programmes.

The university characteristics explored are: type of HEI, number of students, disciplines offered, and programme access requirements (both academic level and whether physics is required). While these characteristics have all been proposed anecdotally as influencing the gender balance of university engineering programmes, others may also be relevant and give opportunity for further study.

3 RESULTS

3.1 Distribution of female engineering undergraduates by university type

Nationally, the proportion of UK undergraduate students who are female across all engineering disciplines is 16%. The value for individual universities ranges from 5% to 36% with Figure 1 showing a bimodal distribution, suggesting there could be two different categories of universities. Differentiating by RG, pre- and post-92, gives not two but three categories, indicated by the colours in Figure 1. This shows that RG universities have, in general, the best gender balance while the newer universities have the lowest percentage of females on their programmes. The values for pre-92 HEIs that are not RG are more broadly distributed. As RG universities all pre-date 1992, the three categories could be reduced to two by combining RG and Pre-92 as 'old' and post-92 as 'new' which would better fit the bimodal distribution.

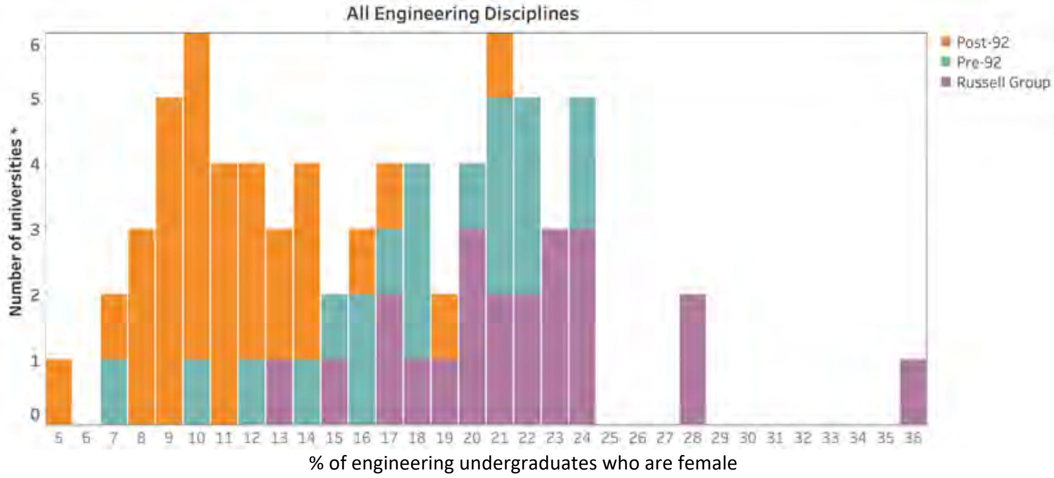

Fig. 1. Distribution of universities by percentage of UK engineering students who are female, indicating university category

The additional characteristics being investigated for RQ2 could be mediating the relationship between the age of the university and the percentage of females on engineering programmes. In addition, as university type is a nominal category, further insight may be gained by exploring some numerical characteristics.

3.2 Engineering disciplines offered

Certain engineering disciplines attract a higher proportion of female students than others (Engineering UK 2020), with the HESA category of bio-, medical-, and biomedical (BMB) engineering having the highest percentage of women nationally. (Prior to 2019, BMB was part of 'general' engineering but, with a change of HESA coding categories, it is now a distinct subset of engineering.)

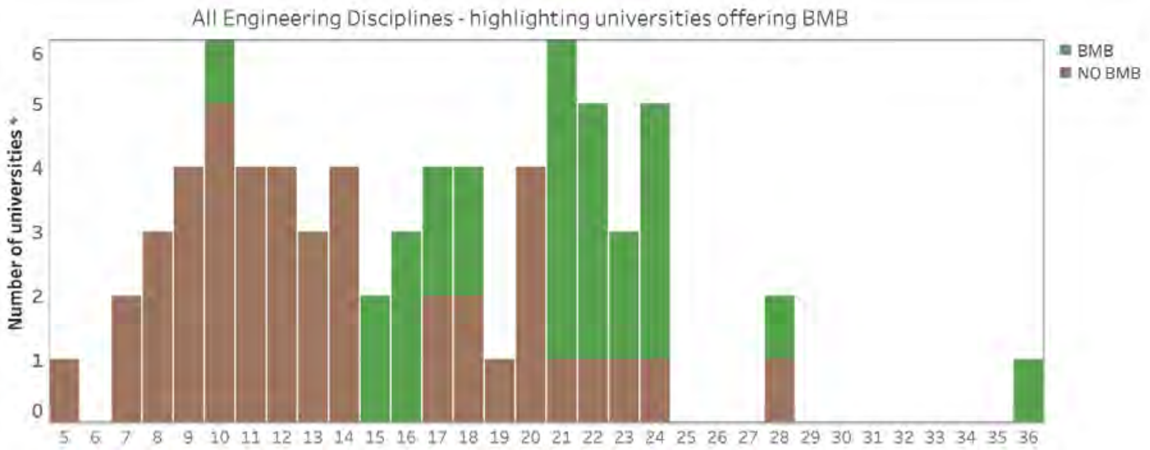

Fig. 2. Distribution of universities by percentage of UK engineering students who are female, highlighting those offering BMB engineering

Figure 2 shows that the universities offering biomedical engineering are likely to have an above average percentage of female students across all engineering disciplines. BMB programmes represent a small proportion of the overall study of engineering but may still provide enough female students to influence the gender balance of an individual university across all engineering disciplines. Offering a BMB programme could also be a mediating factor leading to a higher percentage of females via another mechanism eg a university's offerings being perceived as more cutting-edge.

Analysis of the HESA data shows that the national female representation for the five most populous engineering disciplines is largely repeated at individual university level with the highest female percentages in BMB, followed by chemical, process and energy engineering (CPE), then civil engineering, with electrical and electronic (E&E) and mechanical vying for bottom place. The nature of disciplines offered by a university could influence the overall representation of women on the engineering programmes eg the university with 36% women on its engineering programmes only offers two disciplines, one of which is BMB. It is therefore worth revisiting the university distribution histogram but this time for individual disciplines, once again highlighting the different university types.

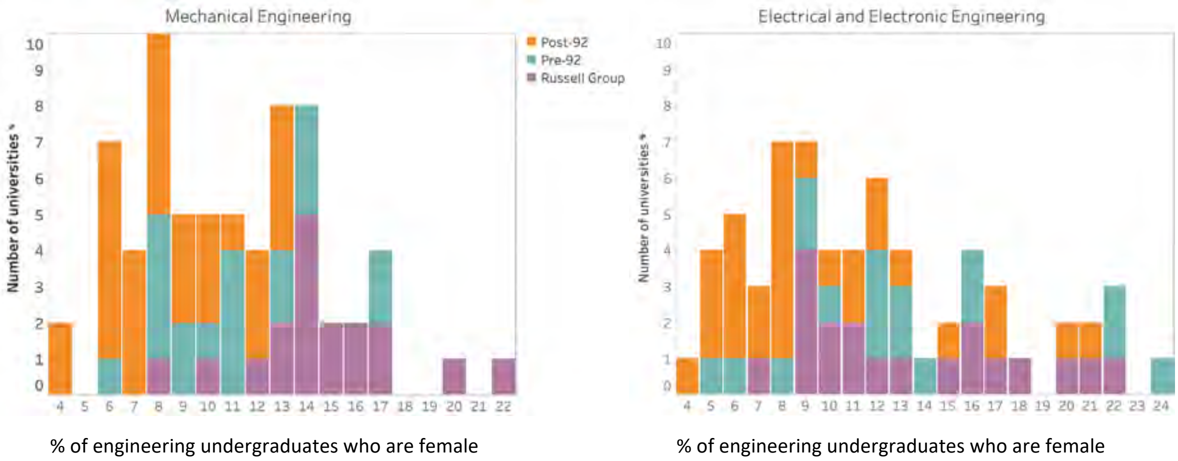

Fig. 3. Distribution of universities by percentage of UK mechanical and E&E engineering students who are female, indicating university category

Of the five disciplines examined, the distribution for mechanical engineering (Fig 3 left) is the closest to the bimodal curve for all disciplines (Fig 1) with a similar representation by RG, pre- and post-92. In contrast, E&E engineering (which, at a national level, competes with mechanical engineering for the lowest representation of women) is the *least* like Figure 1 with a much less distinct distribution of university categories. This suggests that a more nuanced approach is needed to understand why the result for E&E engineering looks so different.

3.3 Number of engineering undergraduates

Another anecdotal suggestion is that the representation of women on engineering programmes increases with the size of the engineering provision, so a larger cohort would be expected to have a higher percentage of female students. Figure 4, where each circle represents an individual university, shows that the 73 universities being investigated have between 495 and 4415 undergraduates (FPE, subject to rounding) registered as studying engineering in 2019/20. As the number of students increases, the distinctions between the 'old' and 'new' universities become more pronounced, with the 'old' universities having the higher percentage of women. Below 1000 students, the picture is much less clear with some small cohorts at 'new' universities getting substantially better female representation than small cohorts at 'old' HEIs. This suggests that whatever the mediating factor is that is leading to the differentiation between 'old' and 'new' universities, there is an additional interfering influence that negates this for smaller cohorts.

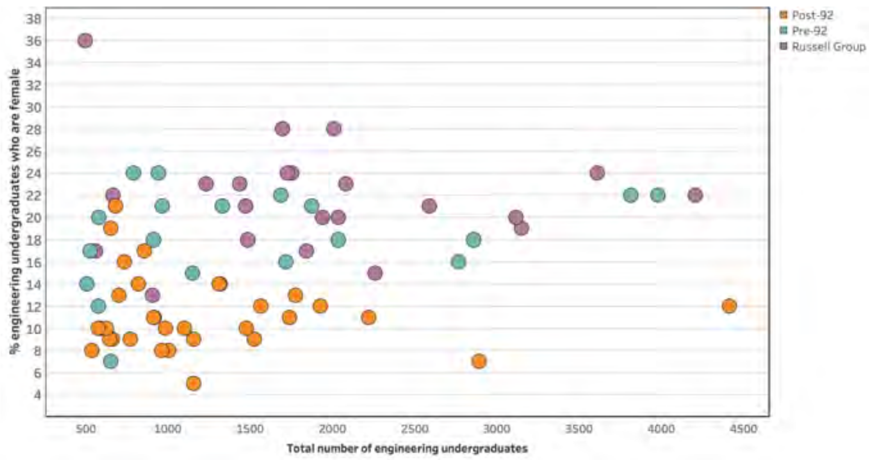

Fig. 4. Percentage of UK students who are female in all undergraduate disciplines as a function of the total UK undergraduate engineering cohort

3.4 Requirement for physics

The underrepresentation of women on engineering courses has long been associated with the low percentage of girls taking A-level physics (Engineering UK 2020). Entry requirements for mechanical, civil and E&E undergraduate courses were gleaned from university websites for the 73 universities under consideration. In most cases maths was a prerequisite, but physics was only mentioned in a list of scientific or numerate subjects of which one was necessary. Thirteen universities had one or more programmes with physics A-level (or equivalent) stated as a requirement, seven of which are in the RG, five more are pre-92 with only one in the post-92 category.

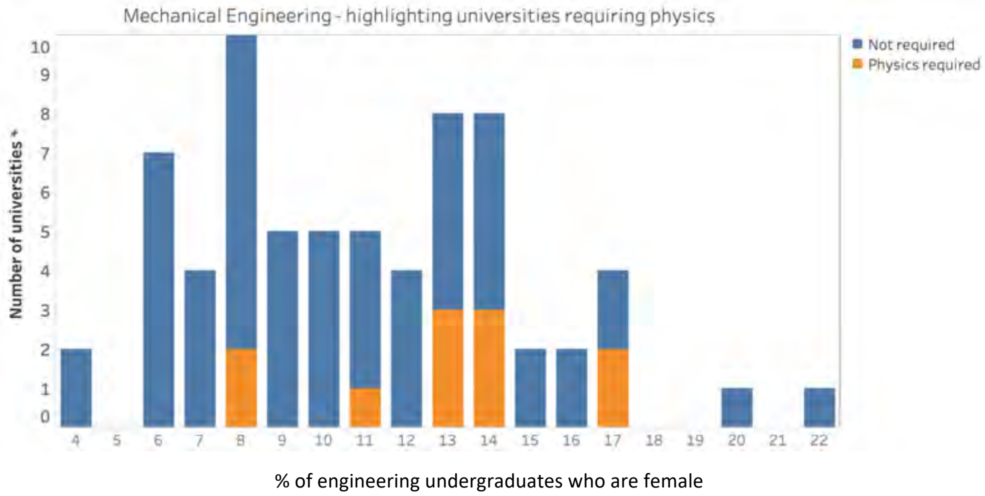

Fig. 5. Distribution of universities by percentage of UK students who are female, highlighting those with a requirement for physics on any engineering programme.

If a university *does* require physics, this is usually for their mechanical engineering programmes. It could be hypothesised that these programmes will have lower percentages of female students, as there is a smaller pool of young women from which the university can recruit. If this were the case, Figure 5 would show the universities highlighted as 'physics required' towards the left tail of the distribution whereas they appear across the breadth of distribution curve, implying the requirement for physics has no clear impact on a programme's gender balance.

3.5 Entry requirements

The final potential mediating variable is the academic achievement required prior to university, ie how good are the student's A-level grades (or equivalent). To make a comparison, the specified subjects are ignored and account only taken of the grade levels required, which are then converted into 'UCAS tariff points' (UCAS 2023). As shown in Figure 6, where each circle represents an individual HEI, students with the lowest tariff will only have access to a small number of post-92 universities. As the tariff achieved increases, gradually more post-92s and then the pre-92s are accessible, with RG requiring the highest tariff points.

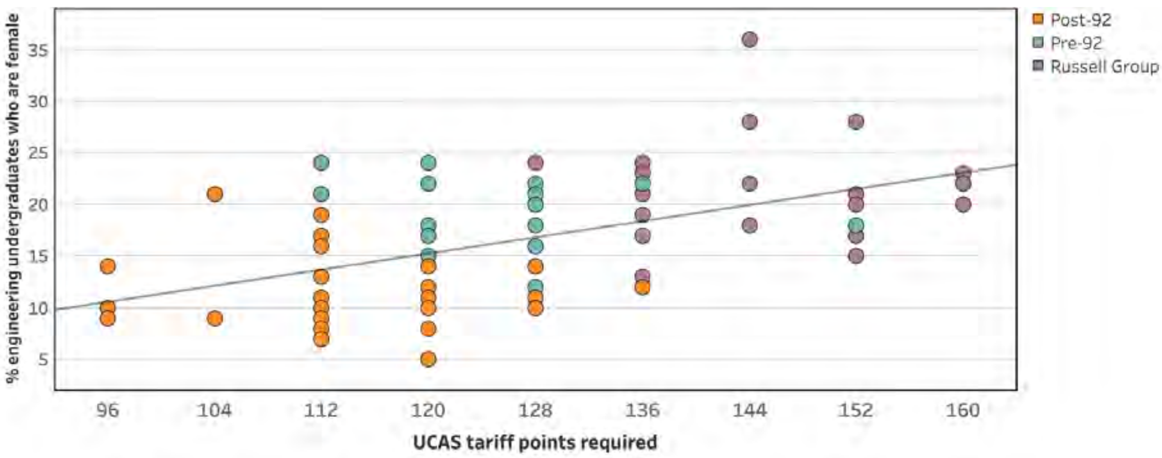

Fig. 6. Percentage of UK students who are female in all undergraduate disciplines as a function of the entry requirements in UCAS tariff points

While caution is necessary when considering regression analysis due to the existence of outliers and because the distribution of universities by percentage of engineering students who are female gives a bimodal rather than a normal distribution, Tableau's line of best fit (p-value < 0.0001) suggests that the representation of women increases with the level of the required entry tariff points. Assuming a relationship exists between the perceived prestige of a university and the tariff required to apply (Foskett 2010), it can be inferred that, broadly, the higher the university's status, the higher the percentage of women on the engineering courses.

4 CONCLUSIONS

The distribution of UK universities by percentage of engineering students who are female (Figure 1) is bimodal, suggesting pre- and post-92 HEIs as two distinct categories. In general, the higher a university's status (equating to academic selectivity) the larger the proportion of women. Female representation is independent of the number of engineering students but is dependent on the disciplines offered by a university. Of the five most populous disciplines, BMB engineering has the highest percentage of women, followed by chemical and civil, with mechanical and E&E the lowest. Only 18% of universities require physics for one or more of their mechanical, E&E or civil engineering programmes and this does not appear to deter female enrolment.

The results support Codiroli McMaster's (2017) identification of a link between family SES and female STEM study, which could be due to the perceived risk associated with breaking stereotypical boundaries. Reduced science (or STEM) capital could also play a role (Archer et al 2015). Females with lower academic qualifications may lack both self-efficacy and identity if engineering is equated with being either nerdy or a genius (Starr and Leaper 2019). Alternatively, perhaps men are *overrepresented* in the 'new' universities - more options may be open to women who possess suitable mathematical ability while also having good verbal skills, while the men with lower verbal skills have fewer options (Wang, Eccles and Kenny 2013).

From a statistical point of view, the best way to improve a university's representation of women in engineering is to drop mechanical and E&E programmes and increase the numbers on BMB courses. Clearly this is not a recommended solution and is a reminder to be wary of quantitative analysis without context. More realistic recommendations for recruiters are to worry less about girls taking physics A-level and to take an intersectional approach when promoting engineering, recognising the different circumstances and priorities of those without the highest academic achievement.

This study has been limited by FPE and rounding in the HESA data and the lack of relevant university categories. Future study could address these issues while monitoring changes in successive academic years both to indicate change over time and to establish natural variation in gender balance within individual universities.

This scoping study has revealed that some universities with lower academic entry requirements have a gender balance equivalent to more prestigious universities, particularly those HEIs with smaller engineering cohorts, suggesting that the individuality and agency of both the HEIs and the potential students merit further study. Future research could go beyond the HESA data and explore the influence of university outreach programmes, 'women in engineering' groups, diversity accreditation such as Athena SWAN, part-time offerings, employer links and placement opportunities etc.

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PREP- Pragmatic Research on Educational Practice

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1 ABSTRACT

We investigate a concept called PREP – Pragmatic Research on Educational Practice, with the goal of engaging engineering educators in studying, documenting and sharing their initiatives to improve teaching practices. This concept is compared to other methodologies where the researcher and educational practitioner sometimes coincide. The study is based on a pilot, with six participants following the PREP program for three months, which we study autoethnographically. We also carried out a focus group discussion (n=12) to investigate to what extent university teachers regard the ideas from the PREP program as helpful for studying educational activities and sharing what they do and find.

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2 INTRODUCTION

2.1 Rationale

University teachers play a crucial role in shaping students' educational experiences and outcomes. They are responsible for creating learning environments that foster student success, including delivering instruction and designing assessments. In the last decades, there has been an increasing emphasis on evidence-based practice in higher education (Groccia and Buskist 2011; Council et al. 2012). However, most teachers involved in engineering education are not educational scholars. They are teaching practitioners that choose their design based on their situation, traditions, preferences, and ideas, less often directly based on research (Slavin 2008). There seems to be a gap between institutional ambitions and the reality for most university teachers involved in engineering education.

On the other hand, our experience is that plenty of ambitious engineering educators try out different pedagogical ideas in their teaching and strive to understand the effects of the implementations to see if they improve the learning experiences, quality, or outcomes in their courses. They do this within the limitations of their time and the course they teach. What they learn from this is often only shared with their closest colleagues.

We believe there is a need for a new form of educational study that can fit the time limitations of higher education teachers. These studies should let them document and disseminate what they already do when working to improve their courses and trying to understand the effects. This goes beyond course development work. It means being part of a community where ideas and results are shared, albeit in a less elaborate format than in regular educational research. It also means committing to being open and transparent about the methods used and the results obtained. To avoid publication bias, it is desirable that also failed attempts are documented and shared.

Results found in this form of study should not be considered equal to regular educational studies and will not generally meet the criteria of educational research journals. For example, due to constraints, teachers cannot be expected to set up control groups, have randomised or large samples, or conduct in-depth interviews. Still, there is value in documenting studies of this form as they will contribute to a pool of outcomes that can be accessed by teachers looking for inspiration and researchers looking for collective patterns. It is also possible that data can be collected from several such projects to be used in more extensive studies. For the individual teacher, benefits include becoming part of a community and turning development efforts into visible merit. For the engineering education community, ideas and results gain exposure, enabling higher-quality education.

In line with this idea, we suggest Pragmatic Research in Educational Practice, PREP (Bengmark 2022).

2.2 PREP - Pragmatic Research in Educational Practice

A PREP study has three characteristics. First, it is pragmatic, i.e. it uses what the engineering educator can see or do within his or her teaching practice, most often within one university course instance. It accepts that ensuring course quality for current students means that the teacher can most often not have control groups or eliminate conflating variables. Second, it is research-oriented in the sense that it is systematic, open, and shared for others to evaluate. Indeed, the main focus is on reporting about the teaching ideas and on what effects are found so that others can replicate or modify and share their result. A single PREP report does not constitute a research paper in the classical sense. However, high scientific rigour can be reached by considering the cumulative results from several PREP reports. An ambition is that when the volume of PREP studies on a specific topic reaches some critical threshold, researchers in education can use PREP studies as part of more rigorous studies of high scientific value. Finally, PREP studies are all about educational practice. They spring from aspects that a teaching practitioner wants to improve or understand by examining educational issues and ideas in their natural environment.

To support the process of conducting PREP studies, PREP groups consisting of a handful of engineering educators teaching during the same period are formed. Each member typically conducts an individual study, possibly in different subjects and at different universities. The idea is that by describing their PREP study and reporting on the progress within the group, the members commit to their studies and prioritise them higher within their work agenda. Also, getting suggestions and ideas from group members can help in overcoming hurdles.

We recommend that a PREP group meet at least three times, in person or online. At the first meeting, the kick-off, each member formulates what they want to try out in their course, some initial thoughts about how the effect should be measured, and ideas on what data should be used. This can be done by answering the following three questions: What am I curious about? What am I going to test in my teaching? What data could help me determine the effect? The other group members react with ideas, suggestions, or references. At the second meeting, mid-course, the members report on their progress, maybe by answering the following questions: What have I done so far? What do I plan to do in the near future? What is stopping me? The other group members help with ideas on how to continue. The third meeting is to support the analysis of the data. Each member describes the data found and their interpretation of it. This is then discussed with the group.

Finally, each member completes their reports. To facilitate this step, reports follow a template filled in online and stored in a designated PREP repository that is searchable and public. The template has the following eight parts: 1. Title; 2. Microabstract; 3. Personal data, including name and contact details; 4. Course information, including subject content, level, size, and a description of the intervention or aspect studied; 5.

The study, including the purpose and study questions, data collection, and analysis; 6. Results and conclusions, such as quotes, graphs, tables, and the author's interpretation of the data; 7. Practical implications such as things to avoid; 8. Other, e.g. references to proven experience or literature. The documentation of a PREP study emphasises the description of the teaching activities, as these need to be understood by educators from other regional or organisational traditions for them to be able to reproduce the teaching activities.

The threshold for publishing, i.e. documenting a PREP study, differs from that of regular scientific journals. For example, unsuccessful or incomplete studies are welcome: as long as they are well-documented, the ideas behind unsuccessful or incomplete studies may interest others. There are lessons to be learned from why a study was not completed. Studies with unclear results are also welcome, as the results may become clearer through replications.

2.3 Research questions

This study investigates how engineering educators view PREP as a tool for studying, documenting and sharing their teaching practice. Hence, we have formulated the following research questions.

- RQ1 What are the benefits of PREP, according to engineering educators, i.e. what aspects of the PREP program do they consider to be helpful for studying, documenting and sharing their pedagogical ideas and practices?
- RQ2 What aspects of the PREP program need improvement, according to engineering educators?

3 OTHER METHODOLOGIES AND PROVEN EXPERIENCE

Several well-established research methodologies focus on improving teaching and learning practices and where the researcher and educational practitioner may coincide. Design-Based Research, DBR, is a methodology that involves the iterative development and testing of educational interventions in authentic educational settings (Anderson and Shattuck 2012). Design Experiments and Design Research are established methodologies that involve the intentional design of educational interventions or systems and seek to generate evidence for the effectiveness of these activities (Cobb et al. 2003). Action Research is a methodology that involves the active engagement of practitioners in conducting research to inform their practice. It uses a cyclical process of reflecting, planning, action, and observing and aims to improve practice through self-reflection and self-directed inquiry (Noffke 2009; Ivankova 2015). Finally, there is the scholarship of teaching and learning (SoTL) which is a process that involves six steps: framing an investigation question, identifying a relevant teaching/learning framework, devising an intervention, conducting the investigation, producing a result with some form of public artefact and inviting peer review (Trigwell 2021).

All these methodologies have similarities with PREP as they involve practitioners and their daily educational settings, not least in Action Research which explicitly involves the practitioner in doing the research, while this may be the case also in the other methodologies. SoTL has significant similarities with PREP as it encourages practitioners to research their teaching. However, there are some major differences. One is that PREP does not expect iterative development within a single PREP study. Iterations are left for consecutive PREP studies, maybe by other authors. In PREP, there is also no need for new designs or interventions. Although this may be the focus in some PREP studies, others may study what is already happening within a course. The main difference compared with all the above methodologies is that PREP moves some of the responsibility for the scientific process from individual authors to the PREP community. An individual PREP study does not meet the scientific rigour expected by studies using the other methodologies mentioned above, including SoTL (Boshier 2009). PREP recognises that university teachers face challenges in finding time and expertise to conduct high-standard educational research. It offers a more pragmatic approach that does not require extensive planning or intervention development. However, in PREP, replications play a significant role. Hence, each PREP study needs a detailed description of the teaching activities studied to make replications possible. Finding patterns among replications and similar studies can be the task of meta-studies. Several PREP studies together can form the basis for more carefully conducted scientific studies.

In practical fields, such as education or health care, practitioners also rely on Proven Experience. This refers to the knowledge and insights gained through years of practice and reflection, shared among colleagues. While proven experience can offer valuable insights and inform teaching practices, it lacks the systematic and transparent nature of educational research. PREP offers a more structured approach that aims to be a systematic and transparent research process together with a structured way of disseminating the results.

In summary, PREP offers a novel approach that engages teaching practitioners in educational research and development at a level less demanding than existing research methodologies but more systematic and transparent than proven experience.

4 METHODOLOGY

Two data sets are collected, one from a pilot where a group of educators followed the PREP program and one from a focus group discussion about PREP with engineering educators.

4.1 The pilot

An autoethnographic study is a form of qualitative case study that explores the researchers' personal experiences and reflections on a particular phenomenon. Data can be collected through a combination of self-reflection, interviews with others, and analysis of relevant documents (Le Roux 2017). This method was chosen to get an inside view of the possibilities and obstacles when studying teaching practices following the PREP process.

A PREP group was formed with six educators from three universities. The group completed a full PREP cycle during a three-month period in the spring of 2023, including the three meetings recommended for a PREP group and the documentation of studies. The four authors of this paper were part of this activity, in this text referred to as the PREP pilot or just the pilot. In focus was what helped and hindered the participants in their attempts to complete their studies and document them. During the process, the authors continuously reflected on how the PREP process influenced their teaching practices and educational research activities. This was subsequently discussed and documented in this report.

4.2 Focus group

A focus group is a qualitative research tool that involves a group of participants engaging in structured discussions facilitated by a researcher. This method allows for an in-depth exploration of participants' perspectives and experiences and promotes group dynamics and interaction that can generate rich data (Gibbs 2012).

A focus group session was conducted as part of a pedagogical conference at a technical university. This was a convenience sample as the participants chose this session voluntarily. At the beginning of the session, the participants were asked for consent to participate in this study. The focus group consisted of 12 university teachers in engineering education from one and the same university, active in various disciplines. Among the participants, three had no prior experience conducting research connected to their teaching, six had participated in studies but never shared educational research results with others, and the remaining three had completed and presented educational research findings at conferences for teaching practitioners.

The focus group session used a structured interview guide developed by the researchers. To let each participant develop their own understanding, the participants were asked to respond to the questions individually first, either digitally or on paper. The interview guide included both multiple choice questions, where the participants had to take a stand, and open-ended questions that aimed at collecting a wide variety of ideas and experiences expressed by the respondents, both concerning engagement in educational research related to their teaching practice and their opinions about the PREP program. The moderator facilitated the discussion, encouraged participants to share their thoughts and experiences, and probed for further elaboration when needed. The data from the focus group session consisted of the answers given in writing and notes taken by the researchers during the session.

The data from the focus group discussion was analysed by the authors and compared with the experience from the PREP pilot.

5 RESULTS AND DISCUSSION

5.1 RQ1: Benefits of PREP

The analysis of the focus group discussion yielded three challenges that engineering educators see regarding their engagement in educational research on their teaching practice. These are lack of time, lack of know-how, and lack of motivation. The focus group data and experience from the pilot both point to aspects of the PREP program that may help overcome these challenges.

The focus group discussion pointed to lack of time as a significant challenge when it comes to conducting educational research. Busy schedules, heavy workloads, and other professional commitments left participants with limited time to engage in educational research activities. Time was also clearly a struggle for the members participating in the pilot. Of the six members of the group, four took part till the end of the process. Three of these have so far completed their PREP documentation, reflecting a lack of time. However, none of them believes they would have had time to complete a regular educational research study during that period.

The focus group found the PREP approach to be simple and time effective as it builds on existing activities. The extra time needed, on top of what is already invested in the course development, is kept to a minimum. Not being expected to do a full educational study makes it more feasible, as many engineering educators do not have time dedicated to educational research in their job description. None of the people engaged in the pilot had special time designated for participation in the PREP. However, using things that they wanted to do as course development, with some additional time invested, four of them completed the cycle. One of the authors that completed the documentation estimated that the time used for filling in the template was two hours.

Another challenge that surfaced in the focus group discussion was the lack of expertise in educational research. Participants felt that conducting educational research required specific skills and knowledge that they did not possess regarding research design, data collection, and data analysis.

That a PREP study is not expected to live up to the high scientific standards of regular educational research reduces the barrier, according to the focus group. Participants found it encouraging that a PREP study may become part of collective evidence together with other PREP studies. The focus group also touched upon the possibility that the lack of expertise can be partly compensated by the collaborative nature of the PREP approach, as colleagues provide ideas and support. Engaging in discussions and receiving feedback from peers may help them refine their ideas and improve their pragmatic research projects. Even if all the members of the pilot had some experience in educational research, they had great help from each other, in particular getting ideas on data collection and suggestions on literature to read.

A third challenge for engineering educators is a lack of motivation to do educational research. As teaching practitioners, the focus group claimed that their main motivation is to develop their teaching. The focus in PREP on educational practice can therefore be a bridge if convinced that engagement in pragmatic research can be a valuable professional development activity that enhances teaching quality. The relevance of the projects for their teaching practice was a great motivator for all members of the pilot. Three of them studied aspects of their ongoing course that they wanted to improve to make teaching and learning better. The fourth member changed PREP projects mid-way in order to shed light on questions raised during discussions at the PREP meetings, using data that had been collected during a previous course but had not been properly analysed and documented.

Another aspect that can boost motivation, according to the focus group, is the social aspect of PREP, i.e. being part of PREP groups. This was definitely the case for the members of the pilot. Knowing that one soon shall tell the group about the progress was often the reason the pilot members took the next steps in their studies, despite very full work schedules.

Finally, the question of recognition was also discussed. Regular educational research is most often recognised in the academic system but takes an effort that is beyond what many engineering educators can muster. On the other hand, doing course development fits into their work life but gives no visible academic reward. That a PREP study in the future could be perceived as a merit within their academic community and contribute to career advancement, was seen as a valuable aspect of PREP for the participants in the focus group. For the members of the pilot, there is not yet much career merit from their PREP studies, but their drive was to contribute to give it recognition in the future.

5.2 RQ2: Improvements needed

During both the focus group discussion and the pilot, aspects of PREP that need improvement were discussed. From these discussions, we have extrapolated two major concerns, scientific rigour and the governing of PREP.

Participants in the focus group expressed concerns about the scientific rigour of PREP studies. Indeed, there was a concern that professional educational researchers or others would object if engineering educators did educational research with lowered standards. One member asked: If a PREP study does not meet scientific standards, what is its value? However, since educational science is a collective negotiation where one research study seldom settles the dispute, there is also a need for reproduction and contrasting views involving many scientists and studies in regular educational science. We argue that PREP studies can contribute to such a negotiation through meta-studies.

In PREP, there is no explicit demand to include references to the research literature. This is provocative, according to some members of the focus group. Not acknowledging what is already known would be unacceptable in regular research. However, the level of connection to previous research in PREP studies may vary. Some might build their study's design on research they refer to. Others may want to replicate an earlier study without delving into the scientific literature that was the foundation for the original study. We argue that such studies should be included as they also have an essential role within the PREP program. On the other hand, meta-studies, using PREP studies as study objects, definitely need a good foundation in the literature.

Hence, if we want to get support for PREP among practitioners and educational researchers, it has to be made very explicit that people involved in PREP are not sloppy researchers. They are practitioners involved in pragmatic research that puts the weight of evidence on the shoulders of the community of researchers. If claims are to be made using PREP studies, it has to involve meta-studies conducted in rigorous scientific manners. It is important that the PREP program does not contribute to a devaluation of the scientific method in the eyes of research colleagues or the general public. Instead, it should contribute to raising the value of educational research among practitioners, and among other stakeholders, as they see teachers striving to understand their teaching practice and a community collaborating and collecting bits of evidence on the effects of teaching practices.

The focus group discussed how the coordination of PREP programs should be organised. There seems to be a need for an organisational body responsible for running a repository, accepting submissions, developing the document template, and connecting people to form PREP groups. This was also discussed during the pilot. The discussions led to the following conclusions.

There is a need to continue to develop the documentation template from its current form to ensure usefulness for both authors and readers of PREP studies. Submitting a PREP study should be as simple as filling in the template online. There needs to be a basic review system to avoid spam and unsuitable material in the repository. Another question is, if and how to evaluate the quality of PREP studies to guide readers. Maintaining and administrating peer review is time-consuming. An alternative could be a system of endorsements or citations by members of the community. Also, the repository should be publicly available, but with login for submissions. It should be well-structured and easy to search, both when searching for a relevant study and when gathering collections of related or similar studies. Each study, or collection of studies, should be easily referenced by researchers in a manner that is stable over time.

The power of sharing data within the PREP community was discussed in the focus group and during the pilot. That would enable using data from many PREP studies to form bigger data sets that can be used for regular research. This was considered an attractive idea with great possibilities. However, it is not included in the PREP program suggested here due to ethical issues which need further investigation.

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TRANSNATIONAL COLLABORATION ON LIFELONG LEARNING BETWEEN HIGHER ENGINEERING EDUCATION INSTITUTIONS: A UNIVERSITY PERSPECTIVE

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ABSTRACT

Lifelong learning (LLL) is in focus in all European countries. Workforce upskilling and reskilling are seen as central elements in ensuring national competitiveness.

Universities are main players in this effort but often find it difficult to find sustainable models for LLL activities, in terms of e.g., economy, student intake, and academic resources. Collaboration between universities can be one possible way forward to overcome such obstacles, and given the enhanced post-Covid digitalization is also increasingly made possible, even across borders. However, many universities also find such collaboration challenging, e.g., due to outdated legislation, lacking financial predictability, lacking

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academic capacity, or other factors. Studies done by the authors indicate that universities' perspectives are seldom present in the literature when barriers and enablers for LLL participation are analysed. This motivates us to particularly consider a university perspective here.

This paper analyses responses to a questionnaire sent to 28 Nordic and Baltic universities, collecting information about successes, opportunities, and barriers for formal (i.e., ECTS-awarding) university-level LLL with professional content within engineering and technology. The respondents were management representatives representing an institutional view and having good knowledge of the institution's LLL offer (e.g., further education centre managers and LLL coordinators). 19 institutions answered, mostly with free text. Our analysis is done following constructivist grounded theory using an open and focused coding approach. The main aim is to identify the main barriers and success factors seen by the universities for upscaling LLL activities, and subsequently to suggest strategies for alleviating barriers and facilitating success factors.

1 INTRODUCTION

Lifelong learning is not a new concept. It emerged in the late 1960s and early 1970's; the European council published a series of 15 studies called *Permanent Education* (Jean-PierreTitz 1995). UNESCO (United Nations' Educational, Scientific, and Cultural Organization) published a report called Learning to be: the world of education today and tomorrow *where the commission laid stress above all on two fundamental ideas: lifelong education and the learning society. Since studies can no longer constitute a definitive 'whole', handed out to and received by a student before he embarks on adult Life, …, educational systems must be thought out afresh, in their entirety, as must our very conception of them.* (p. xxxiii (Faure et al. 1972)). In the early 1990s, there was a renewed interest in lifelong learning, which was observed in both Europe and the United States. This renewed interest was brought about by a new wave of studies and reports that helped popularize the concept of lifelong learning. It also became a topic of national policy discussion, especially as the world faced increasing global competition and economic restructuring towards knowledge-based industries.

Lifelong learning is a broad term that presents a challenge when it comes to defining it in a specific manner. Its association with other similar concepts, including but not limited to lifelong education, permanent education, recurrent education, continuing education, adult education, learning organizations, and the learning society (a society where learning is all-encompassing), adds to this difficulty. While some individuals perceive lifelong learning to involve learning from childhood and early schooling, others view it as an ongoing process of adult education. In the EU, the definition of LLL is: *Lifelong learning encompasses all learning activities undertaken throughout life with the aim of improving knowledge, skills and competences, within personal, civic, social or employment-related perspectives*.(Eurostat 2022) In this paper, we will have a narrower focus on formal learning taking place after a learner's initial education and offered as credit-giving activities by higher education institutions. This is a subset of what the EU calls Adult learning. However, since the general term used in the call for papers is Lifelong learning, we will use that term in this paper.

A lot of research has been done on identifying enablers and barriers for adult learners to engage in lifelong learning (see e.g. (Roosmaa and Saar 2017)). Barriers have been classified as either *institutional* (encompassing institutional practices and procedures that discourage or prevent participation), *situational* (covering barriers tied to a person's life situation), *dispositional* (referring to personality traits or personal qualities) (Cross 1981), or *informational* (lack of availability and awareness of relevant information) (Darkenwald and Merriam 1982). Broadly speaking, although there are nuances and differences between countries, different groups of learners, etc., the majority of studies indicate that the two most important barriers for adult learners to engage in LLL are *time* and *cost*. These two barriers can combine institutional, situational, and dispositional aspects.

However, education providers' perspectives – including research on barriers and enablers for engaging as a provider of LLL offerings - seem to be mostly lacking or are under-communicated in the literature. Most research papers found on LLL seemingly make the implicit assumption that a relevant menu of LLL offerings is already available, and then go on to discuss barriers and enablers for participation as seen from the learners' perspective. Very few studies have been found on barriers and enablers for providing LLL offers, as seen from the providers' perspective (an exception is (Aerts et al. 2020), which studies factors that affect LLL both from the learners', employers', and universities' point of view). Furthermore, very few research papers have been found on how LLL offerings should be designed and delivered to maximize relevance for learners and employers and to stimulate participation.

2 METHODOLOGY

Our main research question is

> *What are the opportunities and challenges linked to (trans)national cooperation on lifelong learning seen from the university perspective?*

The focus of our research is the Nordic and Baltic countries since they have a quite common structure and culture of education.

An obvious way to collect data that can help us answer the research question would be (semi-structured) interviews. However, to get more data points and due to time constraints, we decided to send out a questionnaire with mostly open-ended questions focusing on 1) successes, 2) unused/little-used possibilities for offers, 3) ideas for new offers, and 4) barriers to the facilitation of lifelong learning. All four areas focused on three spheres of influence on lifelong learning: offers where the institution itself controls the offer (called *institutional*), offers where several institutions within the same country influence the offer (called *national*) and offers where several institutions from different countries influence the offer (called *trans-national*).

2.1 Respondents

The questionnaire was sent out to 28 Nordic and Baltic universities, all members of the NORDTEK network (www.nordtek.net). An email invitation was sent to the institution's representative; typically a rector or a dean from the institution. The questions were designed to be most easily answered by a person with good knowledge of the institution's offer within LLL (for example a manager of a further education centre, or a lifelong learning coordinator). If an email invitation recipient judged someone else to be in a better position to answer the questions, (s)he was asked to please forward our invitation to this person.

Table 1: Invitations and answers per country

	Finland	Latvia	Norway	Denmark	Sweden	Island	Estonia	Total
Invited	7	3	4	2	9	2	1	28
Answered	3	3	2	2	8	0	1	19

Apart from the open-ended text questions, a few background questions were added focusing on the use of digital learning in LLL, and the origin of new initiatives for LLL (top-down or bottom-up).

2.2 Analysis

The 19 responses were analysed based on a qualitative exploratory theory, using an open and focused coding approach (Stebbins 2001). The purpose of the analysis was to find common themes for opportunities and challenges wrt. institutional, national, and transnational LLL. As the data was answers to open-ended text questions focusing on the themes, we used a more focused approach to coding than e.g. Charmaz's constructivist grounded theory framework (Charmaz 2014)

3 RESULTS

In this section, we will analyse the responses based on the three spheres of collaboration: Institutional, national, and transnational. In addition to that, we will focus on general questions like the strategic focus of the institutions, and their teaching models.

3.1 General results

Half of the universities have a strategy for LLL. Many of the strategies have a focus on finding ways to "do" LLL. NTNU writes as an example *Action 12: NTNU must clarify responsibilities for its EVU activities* ('EVU' is the Norwegian acronym for 'continuing and further education'). This gives the impression that the institutions are aware of LLL, but it is still in the early stages.

Adult learners have different obligations than "traditional" young students. Thus, more flexible ways of studying are needed, which seems to be something the institutions are also aware of. As seen in *Figure **1***, more than 40% of the institutions offer at least 50% of their LLL online. It looks as if most of the teaching for LLL takes place in a hybrid format.

At the universities, the new initiatives for LLL come mostly from individuals/groups of faculty members but the university management is also initiating LLL activities, see Figure 2.

All of the respondents focus (naturally) on funding. It is difficult to include LLL in the traditional university funding model (typically based on the number of produced ECTS points, graduated students, …). Many of the universities are members of university alliances funded by the EU, where the alliance has (part of) its focus on LLL and thereby funds (part of) the LLL offers. Other examples are funding by learners or businesses, as well as EU/national projects with a special focus on LLL.

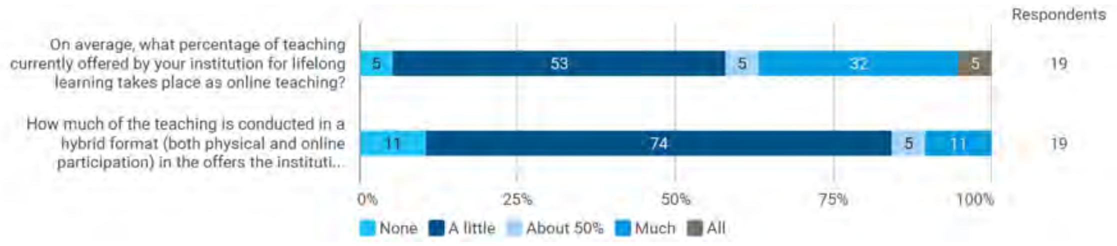

Figure 1: Digitalization in LLL.

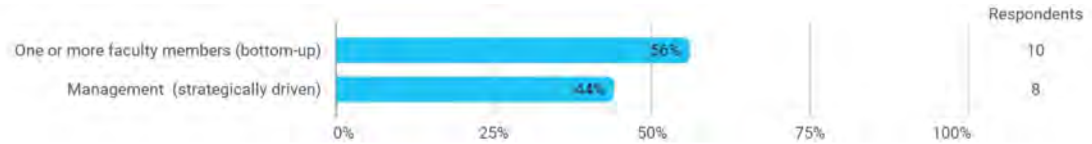

Figure 2 Who initiates new LLL offers?

3.2 Institutional

Success factors and opportunities

All of the universities who answered have experience with LLL. Their discussion of institutional successes mainly focuses on two overarching dimensions: the target group and the delivery method. The degree of success is measured through customer satisfaction surveys, the number of participants enrolling and/or completing, or perceived societal impact. Success factors mentioned include long-term funding predictability, built-in flexibility in - and modularization of - the LLL offerings, active collaboration and relation-building with stakeholders in the private or public sector, cross-disciplinary collaboration between faculties or universities, and professionalization of the university's LLL services (e.g., wrt. marketing and branding, administrative support, development of digital platforms and tools). The same factors were also mentioned by several universities when discussing institutional opportunities (for strengthening LLL) that are so far unused or little used.

Several of the universities have good examples of LLL offers to support the fulfilment of competence demands for targeted professions. Typically, however, these are not in engineering-related topics, but in topics that fulfil requirements for teachers (primary or secondary) or healthcare professionals. There were no reports of successful, institutional offers within engineering, even though all the universities included in the survey have engineering programmes in their regular education portfolio.

The universities also experiment with new ways of teaching within LLL. Several talked about successes when using mobile learning or, more generally, online, asynchronous teaching formats. Several also see experimentation with new delivery formats and pedagogical approaches, including micro-credentials, as one of the so far under-used opportunities for strengthening their LLL portfolio.

One respondent noted that flexible ways of participation could be an opportunity by allowing LLL to participate in "normal" courses on a listen-in basis. It could then be optional for the LL learner to take the exam or not (she could for example obtain a certificate of participation instead).

Challenges and barriers

The absolutely most problematic factor reported by respondents is the financial aspect, which is closely related to the current funding or business models and legislative regimes for LLL, as well as to market needs. There are examples of national rules where some LLL offers are state-funded and some are not, based on the topic – e.g., LLL in engineering is not state-funded, while LLL for teachers and nurses is. The currently available funding models are in general perceived as unclear, unnecessarily limited by legislation issues, not economically sustainable, and not reflective of the changing and increasing demands in LLL. Several of the universities also mention the "culture clash" between their usual "free" education and the LLL "market".

Some respondents also indicate that it is a challenge in itself for universities to track and understand the market needs and demands, both concerning content, format, and scope. This also means that it can be hard for universities to predict the attractivity of a given LLL offering and in particular the development of demand over time. Furthermore, the current development time of new LLL offerings is pointed out as a problem - a shorter time-to-market is needed to match the industry's expectations and needs.

Another common challenge is the lack of institutional resources, especially the time that academic personnel can spend on LLL. Their workload is divided mostly between research and teaching, where the teaching focus is mainly on the "normal" courses and students. Furthermore, respondents note that there are currently no strong incentives or career recognition for most academics to change this *modus operandi* to accommodate more LLL. Some also mention that university teachers typically do not have pedagogical competence on how to teach or supervise learners who are at a later stage of their career.

The lack of a general university strategy for LLL is also mentioned by some as a challenge (see 3.1). It is pointed out by some respondents that such a strategy should involve strong, long-term collaboration with clusters of strategic partners, and a stronger emphasis on scalable commissioned education if it is to be economically sustainable and viable in the long run.

One respondent focuses on the quality of LLL offerings. A lot of free courses have been provided with local or European money, but many of the courses were perceived to be of bad quality. This may demotivate learners from participating in paid LLL courses.

3.3 National

Success factors and opportunities

Some of the institutions have experience in participating in national LLL offerings where they are part of a consortium of universities. Almost all of these experiences reported are positive. Two good examples are the flexible LLL offer from IT-Vest, a collaboration between Aarhus University, Aalborg University, and the University of Southern Denmark (it-vest 2023), and FiTech, a collaboration between seven Finnish universities of technology (FiTECH 2023). Success factors mentioned include the facilitation of a good collaboration environment between participating universities, active national governance and strategy development on LLL, and – as in the institutional case – flexible delivery and modularization of the LLL offerings. For flexibility and modularization, one respondent suggested that there could be value in the development of a joint national platform where smaller LLL modules could be marketed across institutions and chained together in cross-institutional learning paths progressing towards desired competence profiles.

The most important benefit seen by the respondents in going from an institutional to a national LLL offer is the possibility to widen the range of choices for learners so that they can have more chances to fulfil their demands and requirements for competence. This effect is in fact examplified clearly within the field of technology and engineering: Whereas no institutional successes were reported in this field, both the above examples of successes on the national level are within technology and engineering, as are several others. Management, artificial intelligence, sustainability, and digital transformation are also mentioned as topics where there is a market demand or societal need which can be better served through national collaboration.

National collaboration may also lift the burden for each university and make better use of the sparse resources. Some of the respondents find that collaborating with other universities makes it easier to develop and run courses and programmes based on the needs of professional networks and student associations. Lastly, several of the respondents find collaboration (e.g., university alliances) and joint platforms for marketing LLL to be a way to make the offerings more visible to potential students.

Challenges and barriers

Several of the challenges and barriers on the institutional level are also relevant on the national level. The most problematic issue related to national collaboration within LLL is again the financial aspect. Several respondents mentioned the (lack of) stability in the long-term financing of LLL. Some also focus on a (currently unmet) need for a national marketplace or marketing platform for LLL offerings.

Some of the respondents also point to a lack of stable market interest. As one respondent puts it: *When the labour market is cool, there is no money for LLL, when it is hot, there is no time for LLL*.

Competition and fragmentation among universities, the diversity of the higher education sector (consisting of both universities, university colleges, and other types of institutions), as well as national regulation guidelines are also mentioned as barriers. Regulation issues, e.g., accreditation demands, can make collaborations very difficult. In addition, several of the other challenges and barriers which were mentioned on the institutional level also constitute barriers on the national level, e.g., the lack of institutional resources, and the too-long development time of new LLL offerings.

3.4 Transnational

Success factors and opportunities

In general, it is fair to say that not many of the respondents seem to see much potential in transnational collaboration. This is the survey question with the fewest number of answers, and several respondents comment that they do not have a strategy for international collaboration on LLL. However, some point out that a joint platform for marketing LLL offerings could just as well be transnational as national, and that this could give even more shared offers for learners across borders. Sustainability, technology, and digitalization are mentioned as areas where there could be potential.

Furthermore, several of the universities participate in international (notably European) university alliances and mention a potential for LLL collaboration within these alliances. To what extent the alliances - which are still relatively young - will be focusing on LLL remains to be seen, but they do provide an organizational frame around the collaboration. Other respondents give examples of MOOCs where the platform (e.g., FutureLearn) enable the student to choose between several offers from different institutions.

Two respondents have a concrete example of an offer in a “hot topic” (in this case AI), where some of the students can get credits but the offer is open to everyone (from around the world, and at all ages).

One of the universities experiments with micro-credentials, and ways to bundle these into a complete program. They see a collaboration between them and other universities in offering micro-credentials as a way to make more offerings and thereby give students a better and larger choice of topics.

Challenges and barriers

Most responding universities do not yet have a strategy for international/transnational LLL. LLL is in general not seen as very important and where it is, an institutional focus is often seen. Most of the aforementioned barriers to institutional or national success still hold also in an international perspective. In addition, respondents point to the increase in administrative and legislative obstacles (e.g., evaluation of prerequisites for international LL learners, national legislative differences) when one goes international as a potential showstopper for transnational collaboration on LLL. In particular, LLL legislation typically focuses on national requirements and demands which may vary between countries.

Furthermore, understanding the international market needs and matching them to one's institutional strengths is mentioned as a prerequisite for successful international LLL operation.

A final challenge would be to find a way to promote LLL offers across national borders to LL learners. Several mention a current lack of a common, transnational (e.g., Nordic or Nordic-Baltic) platform to promote offers. Also, there is a need for making it easy for learners to collect credits and combine these into a degree if needed.

4 DISCUSSION AND RECOMMENDATIONS

Universities have a long history and are used to slow changes in their student intake. They have been teaching engineers for many years, and have an expectation about the number of new students (and that they will come). This is rooted in the funding model for all the universities in this study. On the other hand, LLL is considerably more unpredictable. Many of the obstacles are focused on how to tackle the dynamic "market" and the more "static" funding models. If universities are to succeed in becoming more active in offering LLL activities, there is a **need for funding models that acknowledge the different circumstances for LLL**.

The tradition from a university is that, once you have a permanent position, you are there "for life". Universities must accept that LLL activities are much more difficult to predict and place in "a five-year plan". **Universities need to be more agile and adjust their resources according to the demand**. It might be argued, given recognized global trends, that this also increasingly will be true for their regular degree programme portfolios.

The regional (or national) market for specialized (technical) LLL activities is small. Many of the universities can see that and are willing to engage in transnational collaborations so that a better balance between supply and demand can be made. In many cases, however, the legislation focuses on national demands and requirements (proving that you have the right prerequisites for a given course is often evaluated by the learner having passed another course, accreditation focus on national demands, teaching must be in a specific language, …). **Easier ways for universities to collaborate transnationally must be established**.

Universities also find it difficult to market their LLL offers. Several good national examples are seen (e.g. FiTECH (FiTECH 2023) or Part-time Master in IT (it-vest 2023)). It would indeed be beneficial if such **LLL platforms are extended to a transnational scope**, or to include more topics.

Universities are (slowly) starting to focus on LLL. The focus so far seems mostly to be on offers offered by individual universities. However, **university alliances (e.g., the European University alliances supported by the EU) can be starting points for transnational collaboration.** This is something that potentially can contribute to overcoming both the low or unpredictable number of students and the lack of teaching resources.

5 SUMMARY AND ACKNOWLEDGMENTS

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CHANGES IN FIRST-YEAR ENGINEERING STUDENTS' PERFORMANCE IN MATHEMATICS AND ENGINEERING SUBJECTS AT DIFFERENT STAGES OF DISTANCE LEARNING

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ABSTRACT

Covid pandemic was unprecedented in modern education but is not expected to be unique, therefore increased attention should be paid to accurately analyse its effects on education. Calculus is an important undergraduate mathematics course in engineering programmes, which gives the foundation for engineering subjects like mechanics or electronics. Unfortunately, recent experiences show that the performance of students admitting after the pandemic has deteriorated dramatically in recent years.

This research aims to analyse the changes in performance and attitudes of first-year students in the aftermath of the pandemic. In our research, we investigated the performance and learning habits of three groups of first-year mechatronics and energy engineering students during Calculus-1 and the related Mechanics subject.

The “2018 group” studied maths traditionally, whereas the “2020 group” took online education in the last months of high school and the first year of university. The “2022 group” spent two years of high school at home in remote learning (the significant 10-11th grades, for maths competence), but received in-person education at the

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university. Learning habit and performance of the students were monitored using EduBase online educational platform.
The results of both the qualitative and quantitative analysis have revealed that online education during the pandemic changed the learning habits of the group in 2020 and had only slight effects on their performance in Calculus and Statics. However, for group 2022, where the pandemic affected high-school maths studies, the performance at the university has fallen dramatically resulting in an increased drop-out rate after the first semester.

1 INTRODUCTION

Covid pandemic was unprecedented in modern education, but is not expected to be unique, therefore increased attention should be paid to analyse its effects on education accurately. At the peak of the Covid-19 pandemic, more than 1.6 billion students were affected by school closures worldwide. Our experiences with the current situation may be helpful in the event of similar cases. As part of the Memory of the World (MoW) Programme, UNESCO (2020) has called on Member States to increase the documentation of information on Covid. Four key areas have been identified: documents based on educational, social, scientific and artistic values. In response to this call, several studies have been published, and it is widely accepted that lock-down cause significant losses in education (UNESCO 2020), (Kuhfeld and Tarasawa 2020), (Kuhfeld et al. 2020).
There are serious concerns that short-term learning losses experienced immediately during the lockdown and online education may continue to accumulate as students return to school, leading to significant and lasting losses. Andrabi et al. analysed the effect of the earthquake of 2015 in Pakistan four years after the earthquake, comparing households close to the fault line with those further away that was not affected by the earthquake. Schools in the affected area were closed for an average of 14 weeks. Four years later, however, children living in the affected areas were not only three months behind but had the equivalent of a 1.5-year lack of schooling (Andrabi et al. 2021)

1.1 The effect of Covid on engineering higher education

Several analyses have also been published on the impact of the COVID-19 epidemic on university education and students' performance. The lockdown and online education have particularly affected engineering programmes with a large number of laboratory and practical subjects, which are effective in a traditional, face-to-face format. One of the most important aftermaths was the decrease in knowledge levels. Online teaching made it difficult for students to concentrate, and many found it difficult to adapt to the digital learning environment. The lack of interactivity and relationships between students also had a negative impact on students' mental state and learning outcomes. After the lockdown of the dormitories, many students felt isolated and had fewer opportunities for social interaction. Emotional stress and loneliness also affected the students' mental health.
Additionally, institutions were not sufficiently prepared to detect fraud following the sudden changeover. In several cases, this led to exceptionally good results compared to previous years.
However, the impact of the Covid pandemic varied between different groups of students. Students who had financial difficulties or who did not have a suitable learning environment (e.g. internet access, IT devices) at home faced greater challenges than those who had better a comfortable learning environment at home.

In the recent study of Kaffenberger the long-term effects of Covid are investigated on the education system (Kaffenberger 2021). Kaffenberger attempts to make predictions about the long-term consequences that the education system may face due to the learning disruption caused by the pandemic. It is predicted that learning disabilities may have long-term effects on student achievement and social inequality. The article suggests measures that should be taken to avoid such long-term consequences, including digital education, expanding educational services and improving educational infrastructure, which could improve student achievement and reduce social inequalities.

1.2 Motivation and goals

In Hungarian higher education Calculus is the most important undergraduate mathematics course in engineering programmes, which gives the foundation for engineering subjects like mechanics or electronics. It is important to mention that in Hungarian engineering higher education, Calculus is typically taught over 3-4 semesters, and includes also topic of algebra, linear algebra and differential equations. Unfortunately, recent experiences show that the performance of students admitting after the pandemic has deteriorated dramatically in recent years.

In our research, we investigated the results and learning habits of three different groups of first-year mechatronics and energy engineering students during Calculus-1 and the related subjects in Mechanics: i) the “2018 group” called pre-COVID, ii) the “2020 group” called COVID-group with online education and iii) the “2022 group” called post-COVID group.

In 2018 the “pre-Covid” students’ secondary school and first-year university studies were not affected by the pandemic. The class of 2020 received online education from March to May in their final year of high school, and this continued in their first year of university. The third group started university in 2022 in attendance education and received online education in the last two years of high school. These two years are when Hungarian students can choose the two subjects that are relevant for their further studies and study them in higher contact hours in advanced level.

In Hungary, the university admission procedure is partly similar to that in many Central and Eastern European countries, as students take a nationally standardised A-level exam at the end of secondary school. Each university determines which subject results are accepted during the admission process. In engineering higher education, this is typically physics, computer science or chemistry. The aim of the A-level exam is therefore to test the knowledge required for the chosen higher education programme. The A-level exam can be taken at advanced or intermediate level. The results of the A-level exams are converted into points and, together with the additional extra points (e.g. for language certificate, national competitions), are evaluated on a 500-point scale.

In the first week of the semester, first-year students at our university take a mathematics entrance test consisting of 15 four-point multiple-choice questions from the level of the intermediate mathematics examination. For the first semester Calculus in Mechatronics, the minimum score required is 25 points.

2 DATA

In this study, three different classes of the mechatronics and energy engineering courses were investigated through their performance and learning habits in the Calculus 1 course. The number of groups and the results of the admission and entrance tests are summarised in Table 1 and Fig. 1.

Table 1. Participants of the investigated Calculus 1 course

	2018	2020	2022
Number of students	120	134	173
Average entrance points	458.62	445.96	454.71
Standard deviation of entrance point	23.22	30.20	26.78
Average of entrance test (Test 0)	39.38±10.71	46.02±8.84	36.14±12.04
Percentage of Passed at Test 0	12%	97%	18.5%
Percentage of Failed at Test 0	88%	3%	81.5%

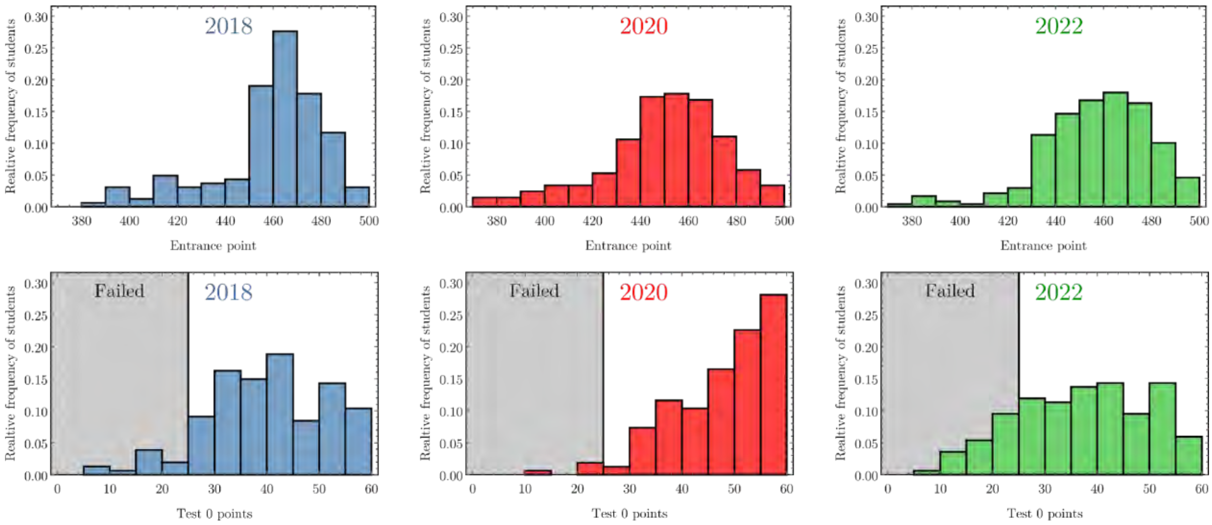

Fig. 1. Relative frequency of a) entrance points and b) entrance test (Test 0) results for all classes 2018, 2020 and 2022

2.1 The “2018 group” – pre-Covid

In the class of 2018, 118 students were admitted to mechatronics (admission point: 451) and 46 to energy engineering (admission point: 389) programmes. The students included in our study are those who took the basic Calculus 1 course. This means 120 students with an average admission score of 458.62 points and a standard deviation of 23.22 points.

Since nearly all students studied mathematics at an advanced level in high school and furthermore, many of them took advanced A-levels, thus they had no problem in meeting the 40% minimum on the entrance test (Test 0). Only 12 students failed to achieve the required 25 points.

2.2 The “2020 group” – Covid

In the class of 2020, 162 students were admitted to mechatronics (admission point: 433) and 77 to energy engineering (admission point: 349) programmes. The students included in our study are those who took the basic Calculus 1 course. This means 134 students with an average admission score of 445.96 points and a standard deviation of 30.20 points.

This year, students took the mathematics entrance test (Test 0) online in their homes using the Moodle system of the University. The results were unlikely too good. More than 50% of students got excellent results (above 85%). Only 4 students scored below 40%, one of whom achieved 100% on the make-up test, also online. The results of this assessment cannot be considered relevant to our study.

2.3 The “2022 group” – post-Covid

In the class of 2022, 227 students were admitted to mechatronics (admission point: 429) and 73 to energy engineering (admission point: 348) programmes. The students included in our study are those who took the basic Calculus 1 course. This means 173 students with an average admission score of 454.71 points and a standard deviation of 26.78 points.
In 2022, the entrance maths test (Test 0) was very poor. Out of 173 students, 32 students failed to score at least 25 points on the in-person test. However, on the several make-up possibilities, most students passed this test. This year was the first time that students who had not studied advanced mathematics in high school.

3 RESULTS

The EduBase online learning platform, which has been used successfully in mathematics education for almost 10 years, allows us to monitor not only the effectiveness of our teaching but also the time students spend learning (www.edubase.net 2023), (Szilágyi et al. 2020), (Berezvai et al. 2019). Both interactive exercises and homework assignments from calculus subjects are available through EduBase. Students receive homework assignments on a weekly basis and also have the possibility to do further exercises. As we have parameterised exercises, a virtually infinite number of exercises are available in any topic of the subject. In a previous study, we analysed the variation of practice time for the first-year class of 2020 and it was found that the average time did not decrease as the semester progressed, in contrast to the pre-pandemic experience, when students did not have enough time to practise in the last weeks of the semester and only did homework (Sipos et al. 2022).

In 2016, with the introduction of EduBase in Calculus education, the aim was to change students' campaign-like learning habits (reduced to the days before tests and exams) and move them towards distributed learning pattern (where the student works on the course material during the whole semester, preferably several days a week).

3.1 Analysis of learning habits

In each of the following figures, the blue colour indicates the “pre-Covid class” starting in 2018, the red colour the “Covid class” starting in 2020 and the green colour the “post-Covid class” starting in 2022. The figures illustrate how the Calculus 1 homework submissions and learning times evolved throughout the three investigated semesters.

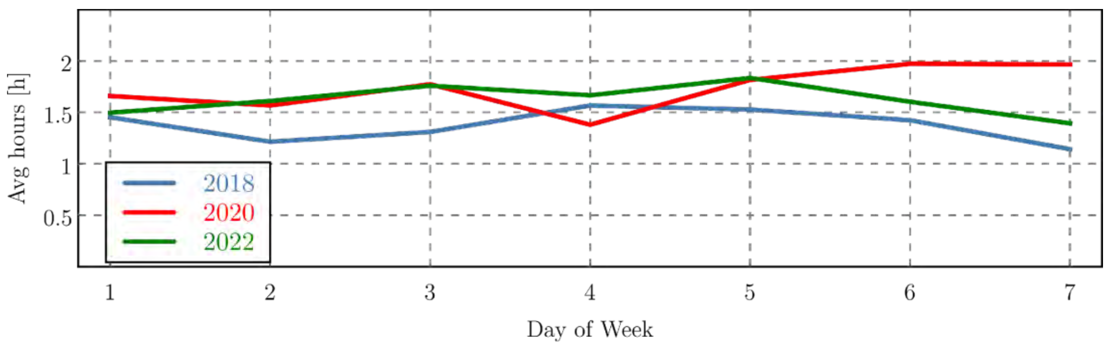

Fig. 2. Average time spent on homework per day of the week for each class

Figure 2 shows the average time spent on solving homework by day of the week. It can be clearly seen that the classes affected by Covid (2020 and 2022) spent more time on solving homework, which can be explained by the weaker input parameters (incomplete basic knowledge, lower average skills, lower admission scores). Note that the pre-Covid and post-Covid classes show a similar trend. During the pandemic, weekends were merged with weekdays. The elimination of weekend social and family programs increased the probability of solving homework on weekends.

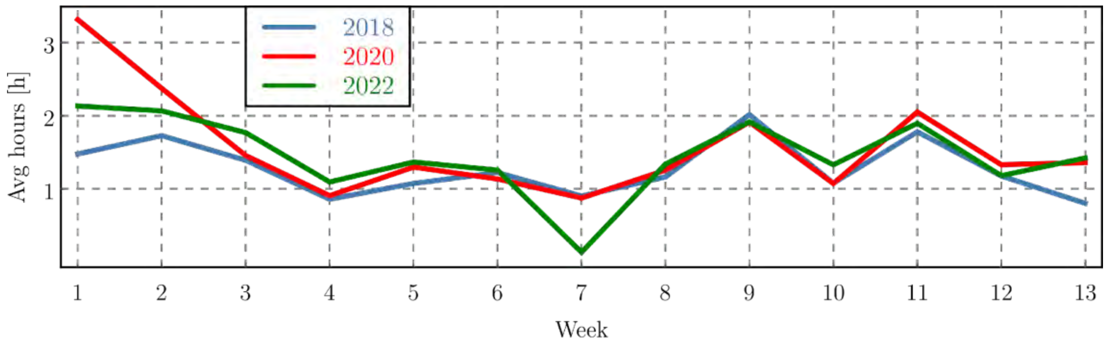

Fig. 3. Average time spent on homework per week of the semester for each class

Figure 3 shows the time spent on solving homework by week during the semester. The high learning time of the first week of the 2020 class (red curve) is related to the topic of Analytic geometry, which covers a lot of the material from high school and which was emphasized in the online high school education and therefore, students needed more time to complete their homework in comparison to the other classes. The low value of the 7th week for the 2022 (green) group can be explained by the fact that there are midterm tests in almost all subjects, and for this group this became so stressful that there was less time to complete regular homework.

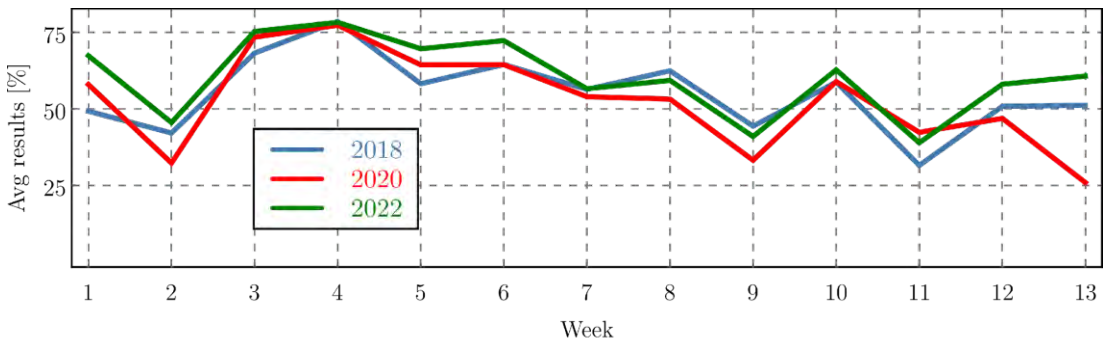

Fig. 4. Average performance of homework per week of the semester for each class

Figure 4 demonstrates the effectiveness and shows interesting results that might seem contradictory. It is perhaps surprising to see the relatively good performance of the "2020 group" most affected by the pandemic. Still, it is worth looking at this in conjunction with Figure 5, which shows the proportion of homework submitters as a function of time. For the Covid group (red curve), it can be seen that the number of submissions is decreasing, and the success rate is also lower. For them, however, we found that the practising throughout the semester was balanced, which may explain the smaller drop in their performance on the tests.

Figure 6 shows the percentage of days on which students submitted the most homework. It can be seen how the pre-Covid (blue) and post-Covid (green) groups tend to deal with homework immediately before the Monday deadline, while the Covid group (red) had a higher submission rate after the seminar days (Wednesday and Thursday). This can be explained by the heavy workload during the year, with many contact hours. During in-person education, our students usually spend a lot of time on campus. Looking also at Figure 2, it can be seen that on a daily basis, students studying in attendance spent more time completing the homework on weekdays and left the submission for the weekend.

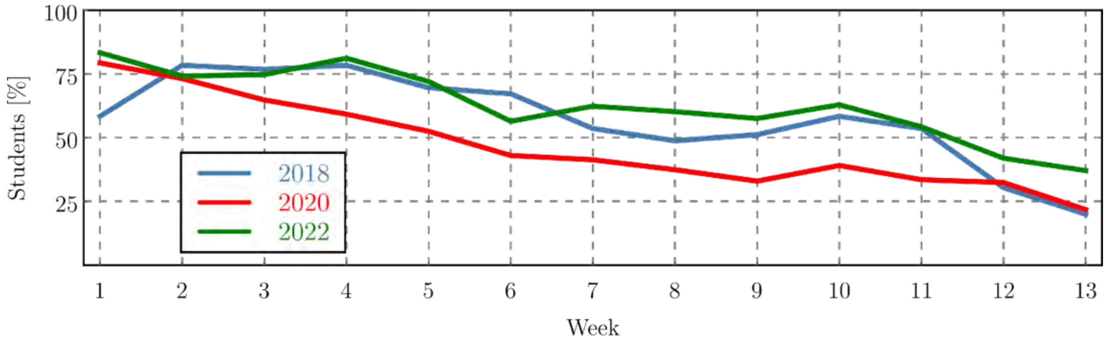

Fig. 5. Percentage of students submitting solutions per week of the semester for each class

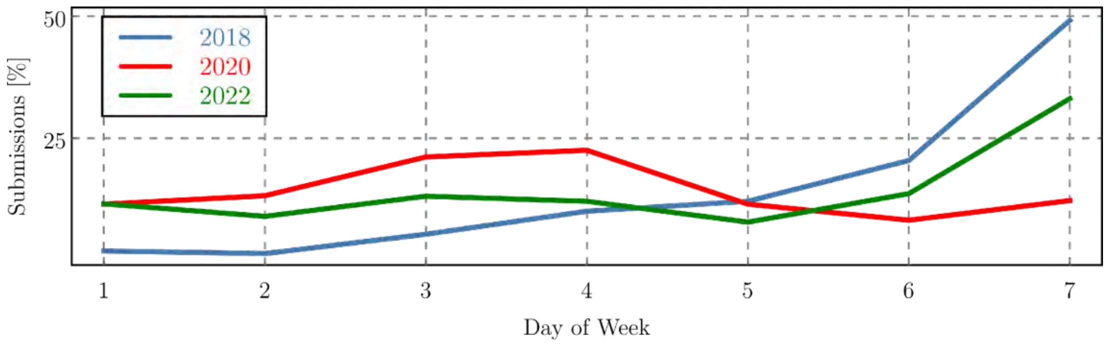

Fig. 6. Percentage homework distribution per day of the week for each class

3.2 Analysis of performance

In the following, the performance of each class was assessed using Calculus and Statics results. Statics is also a mandatory course in the first-year curriculum, which covers the basics of Mechanics including the concept of force-systems, equilibrium, stress-resultants etc. This subject is considered to be most "Math-based subject" as the students are expected to apply the mathematical techniques, they learned in Calculus 1 when solving statics problems, (e.g.: 3D vector operations for force system reduction, differentiation and indefinite integration of stress resultant functions, definite integration for centre of mass calculations). Statics tests always consist exclusively of numerical problems, which can be used to test not only mechanical but also mathematical knowledge. The statistical results of each test are summarized in Table 2. In Figure 7, the first two rows show the results of the first and second tests in Calculus 1, while the last two rows show the results of the first and second tests in Statics (there was no second test in Statics in 2020). If we compare the distribution of the test results and the entrance point distribution in Figure 1, it can be clearly seen that there is an increasing spread in the admission scores, which also means that the knowledge of the cohort is becoming more heterogeneous. The negative effect of the pandemic is clearly visible in the Calculus 1 results. The distribution of the pre-Covid and Covid year classes is still similar, but a slight difference in the mean value is observable. For the post-Covid group, a significant increase in poor results is clearly detectable. For the first Statics test, we also see an increase in the proportion of poorer results. Whereas for Statics Test 2, the results are notably different from the others: the post-covid results show a small improvement compared to the pre-covid results. This deviation is due to two reasons: i) Test 2 usually consists of easily algorithmizable tasks, and ii) after the failures in Test 1, students were given extra preparation materials and online practicing opportunities as an intervention, which could have helped them to reduce the deterioration of the results.

Table 2. Statistics of the Calculus and Statics test results

		2018	2020	2022
Calculus Test 1	Average	64.14±14.17	47.08±17.29	41.89±24.15
	Failed	4.16%	30.93%	40.31%
	Good result	30%	11.04%	10.47%
Calculus Test 2	Average	61.61±17.43	55.02±18.56	25.07±21.03
	Failed	5.83%	13.25%	69.10%
	Good result	21.66%	23.21%	2.09%
Statics Test 1	Average	68.16±18.82	61.50±26.13	51.27±23.89
	Failed	5%	17.29%	30.81%
	Good result	49%	39.84%	23.25%
Statics Test 2	Average	53.36±27.47	N/A	58.57±29.52
	Failed	27%	N/A	23.12%
	Good result	30%	N/A	45.08%

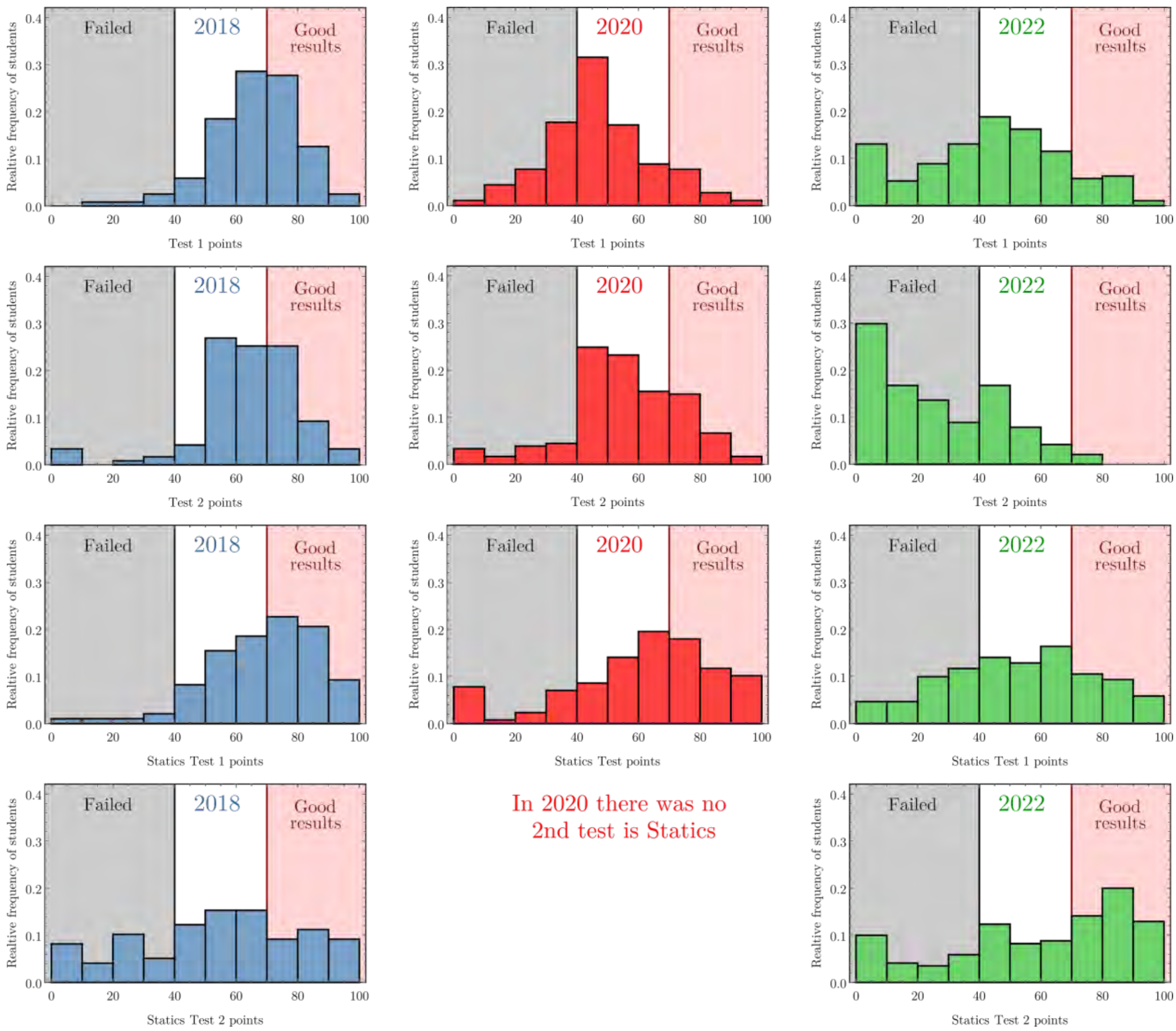

Fig. 7. The relative frequency of Calculus and Statics test results

4 CONCLUSION

In our paper, the impact of the pandemic on three different groups of students was revealed. It can be concluded that Covid has a severe and a long-term impact in engineering higher education. Since online education affected the entire school system, the effect of Covid due to the insufficient mathematical education in elementary or high school will be a long-lasting phenomenon in the future. However, we cannot stop at detecting the effects, and we need to take measures to reduce the negative impacts. At the Budapest University of Technology and Economics, we see the need to provide a catch-up course in addition to the self-study materials, which. have already been implemented in the spring semester of 2023. The analysis of the results is still ongoing as the semester is not finished yet, but the first impressions shows that the intervention had a promising result and seems to be an adequate help to compensate for the handicap caused by the pandemic.

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ENGINEERING STUDENTS' DYNAMIC AND FLUID GROUP PRACTICES IN A COLLABORATIVE DESIGN PROJECT

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Conference Key Areas: *Engineering Skills and Competences, Fostering Engineering Education Research*
Keywords: *Design project, Collaborative learning, Group practices, Video ethnography, Interaction analysis*

ABSTRACT

There is a growing interest in engineering education that the curriculum should include collaborative design projects. Collaboration and collaborative learning imply a shared activity, a shared purpose, a joint problem-solving space, and mutual interdependence to achieve intended learning outcomes. The focus, in this study, is

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on engineering students' collaborative group practices. The context is a design project in the fifth semester of the problem-based Architecture and Design programme at Aalborg University. Students' collaborative work in the preparation for an upcoming status seminar was video recorded in situ. In our earlier studies video ethnography, conversation analysis and embodied interaction analysis have been used to explore what interactional work the student teams did and what kind of resources they used to collaborate and complete the design task on a moment-moment basis. In this paper we report from a one-hour period where a group of four engineering students do final designs in preparation for the status seminar. Using recorded multi-perspective videos, we have analysed students' fine-grained patterns of social interaction within this group. We found that the interaction and collaboration was very dynamic and fluid. It was observed that students seamlessly switched from working individually to working collaboratively. In collaborative work students frequently changed constellations and would not only work as a whole group, but also would break into subgroups of two or three students to do some work. Our results point to the need to investigate group practices and individual and collaborative learning in design project groups and other collaborative learning environments in more detail and the results challenge a naïve individual-collaborative-binary.

1 INTRODUCTION

1.1 Importance of design education in engineering

The ability to develop and design products, processes and systems and demonstrate the capacity for teamwork and collaboration have become essential requirements for an engineering degree in many countries. For example, the Swedish national university regulations require that to be awarded an engineering degree, students must "demonstrate the ability to develop and design products, processes and systems [and] demonstrate the capacity for teamwork and collaboration". For this reason there has been a growing interest that engineering education should include collaborative design projects and this requirement is included in the CDIO-standards (e.g. Crawley et al. 2014; Edström and Kolmos 2014)

Given that design-based learning activities have become a key component in engineering education, there is a need to better understand students' learning processes within design projects. Moreover, within design projects it is also important to better understand how students develop the "capacity for teamwork and collaboration", i.e., how they become skilled in collaborative design work.

1.2 Teamwork and collaboration

However, collaboration and cooperation are often not always clearly distinguished and the nuances are often lost in the definition of the concepts. In line with (Dillenbourg 1999), Stahl (2013, 2016), and others, we see cooperative learning as an activity there students divide up group work and then put the individual contributions together, whereas in collaborative learning students do the work together. Collaboration and collaborative learning implies a shared activity, a shared purpose, and a mutual interdependence to achieve the intended learning outcomes (Dillenbourg 1999). Stahl (2013, 2016) argues that in studies of collaborative learning it is important to focus on small group phenomena and to use the group as a unit of analysis. According to Stahl, collaborative groups build knowledge through shared understanding, co-construction, and interaction in a joint problem space. Furthermore, he proposes that studies on teamwork and collaboration build on post-cognitive theories. Thus, a project group in a collaborative design project can be seen as a community of inquiry. Indeed, students' cognition in an engineering design project (Brereton 2004) has been seen as an example of "distributed cognition" (e.g. Goodwin 1995; Hutchins 1995), since achievements do not only arise from individuals thinking, but also through collaborative thinking distributed among the members in the design team *and* from the use of epistemic tools (Goodwin 2018).

1.3 Short literature review and our earlier studies

Although more than 30 years has passed since Tang and Leifer (1991) argued for the use of video recordings and interaction analysis (Jordan and Henderson 1995) to study group design activity the dominant empirical method to investigate *students'* design processes have until recently been variants of "think-aloud" exercises with verbal-protocol-analysis (Craig 2001) mostly with *individuals* in *artificial* settings (Bernhard, Edström, and Kolmos 2016) with tasks that were completed in rather *short time*, i.e. one to two hours (e.g. Atman et al. 1999; Atman et al. 2007; Cardella et al. 2008). To our knowledge, Campbell, Roth, and Jornet (2018) seem to be one of the rare cases that, beside our own studies have studied engineering students' design *process* using interaction analysis. There exist, however, studies using other forms of ethnographic methods to investigate students' design process in naturalistic educational settings. For example, using audio-recordings (e.g. Gilbuena et al. 2015), video-recordings (e.g. Goncher and Johri 2015; Campbell, Roth, and Jornet 2018), and photos and field-notes (e.g. Juhl and Lindegaard 2013).

In our own previous studies, we have made video-recordings and studied a design project in the fifth semester of the PBL-based Architecture and Design programme at Aalborg University. We found that the fifth semester students displayed epistemic fluency (Markauskaite and Goodyear 2017) by fluent use of a rich repertoire of bodily-material resources, working both "by hand and by computer", as epistemic tools to think collaboratively in design activities (Bernhard et al. 2019; Bernhard, Davidsen, and Ryberg 2020; Ryberg et al. 2021) and develop a professional dialogical space that is not only being manifested in verbal discourse but also in the previously mention resources (Davidsen, Ryberg, and Bernhard 2020). Moreover, we have analysed and discussed the different knowledge forms embedded and emerging in students' collaborative and embodied interactions (Ryberg, Davidsen, and Bernhard 2020).

In the literature regarding collaborative learning the *composition* of the studied collaborative group(s) is commonly static and does not change (e.g. Borgford-

Parnell, Deibel, and Atman 2013; Menekse et al. 2017). However, when we were analysing videos of students' interactions in our earlier studies we also noticed that students approached a particular design problem in shifting subgroups of one, two or three students or as a whole group. This implied that the collaborative group, indeed, was not static. As this, to our knowledge, was not well discussed in the literature we, in a recent study (Bernhard, Davidsen, and Ryberg 2023), investigated the dynamics of collaborative work in students' group practices in a design project. We found that the patterns of collaboration were not static, but indeed displayed a myriad of different patterns. Also the group members transition in and out of 'private conversations' and dialogue about the design.

In this study we focus the dynamics of individual and collaborative work by the four female students in the group that was carried out for an hour starting 44 minutes into the group's meeting. This part was selected as it displayed a rich and fluid repertoire of individual and collaborative work in different constellations. Our research question was *how could we describe and understand the dynamics of students' individual and collaborative work in the studied one hour of a design meeting?*

2 SETTING AND METHODOLOGY

2.1 Setting

The setting of this study is the Architecture and Design (A&D) programme given within the frame of the Aalborg problem-based learning (PBL) model which was created in response to the call that engineering programmes should include collaborative design projects of varying length and complexity. The A&D programme includes elements of architecture education, but also builds on knowledge, skills, and competencies from engineering. In the Danish context this was a novel approach when the programme started in the 1990s, as traditionally the fields of architecture and engineering are separated. The creation of the A&D programme was an attempt to combine the "technical theoretical" knowledge of engineering with the "aesthetic and artistic" artisanship of architecture, to create a new interdisciplinary education.

The data analysed in this paper is from a period 14 days into a project work where fifth semester A&D students are tasked with designing an office building for an external partner. The particular session studied is where a student group (group 3: four females, two males) is preparing to take part in a formal review session the next day. After the review session the groups have approximately four weeks left to complete their design of the building. The preparation for the review session was selected for analysis as it is what Jordan and Henderson (1995) refer to as a natural unit of analysis – limited in time and with a particular purpose.

The main workspace for the group was encircled by a fixed wall with windows, and two "walls" consisting of whiteboards, pinboards and blackboards. One of the "board walls" is used for various design ideas and sketches with each board having a particular type or category (e.g., printed computer designs or drawings). The other board wall is used as a calendar and overview of tasks (with different colourcodings). In the midst of the group space is the “working table”, which is littered with paper, sketches, laptops, models, iPads, bottles etc.

2.2 Data collection and method for analysis

To achieve a rich picture of students’ individual and collaborative work and enabling studies to increase our understanding of engineering students’ learning processes in collaborative design projects we have recorded the interactions within the group using five digital camcorders (including one body-mounted GoPro camera) during the complete session (Jordan and Henderson 1995; Heath 2016; Goodwin 2018; Tang and Leifer 1991; “Big Video”, e.g. Mcilvenny and Davidsen 2017). In this case the session lasted almost six hours. In this study we have focused on the work, and interactions, by the four female students in the group that was carried out for an hour starting 44 minutes into the group’s meeting. This part was selected as it displayed a rich and fluid repertoire of individual and collaborative work in different constellations.

Fig. 1. Still pictures from videos displaying first individual work (pictures a and b)and a transition to a dyad between Ina and Mette (c and d).

For the purpose of this study recorded videos were viewed and analyzed by coding in which constellations students worked (e.g., individually, in subgroups, or in whole group). Furthermore, students’ membership in subgroups were noted, and it was noted the time constellations changed. To count as a member of a constellation a student had to actively display participation either verbally or bodily. Fig. 1 display a transition from individual work by all female students to a dyad between Ina and Mette and continued individual work by Sine and Heidi (corresponding to episodes 19 and 20 in Fig. 2). It should be noted that the students speak Danish and students’ expressions have been translated to English. The first author is a native Swedish speaker, but understands Danish quite well and the second and third authors are native Danish speakers.

Although parts of the videorecorded interactions have been transcribed, the transcripts have not been used in this part of our analysis. The reason is that standard transcripts primarily display the verbal part of interactions and to identify collaboration patterns we found it to be essential focus on embodied interaction.

The study was conducted under the ethical guidelines in place at Aalborg University and at Linköping University in accordance with Danish and Swedish laws. Informed consent forms were signed by each research participant. In this paper, participants have been given pseudonyms to protect their anonymity.

3 RESULTS

3.1 General findings

Before the analysed session the students had eaten breakfast together and as whole group (including two male students Anders and Sven). As one of the female students, Heidi, has just returned from being away there is a lot informal talk in the beginning. At the beginning of the work session the two male students leave the main room to work with their tasks at another place while the four female students remain at the groups main working space. For an hour (actually an alarm clock is set to mark timings) they work together in shifting constellations. An overview of the coding of the constellations is displayed in Fig. 2, with each student colour coded. Contrary to our previous study, in this study we have also included students' individual work in our coding as represented in Fig. 2. After the hour the group splits up and Sine and Heidi leaves the room at 1:44 while Ina and Mette remain in the room and work together until lunch-time. At 3:20 the whole group reconvene first to eat lunch together and after finishing lunch to coordinate and finalise designs and plan the presentation during the upcoming review seminar. An overview of the whole meeting can be found in Bernhard, Davidsen, and Ryberg (2023).

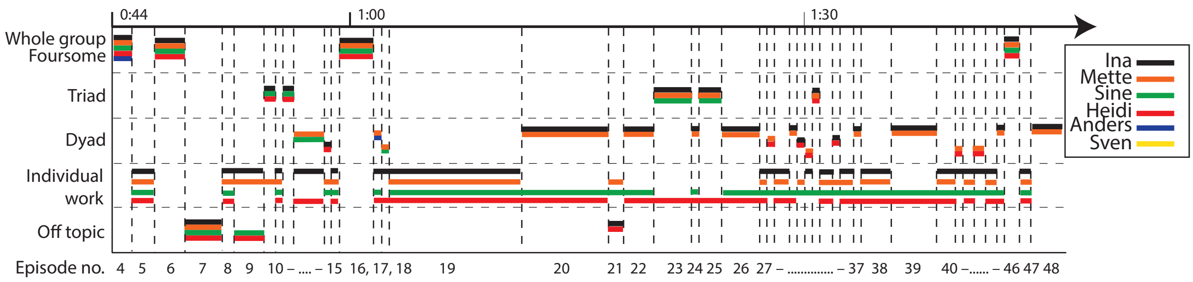
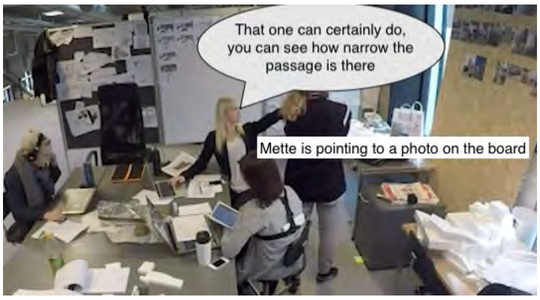


Fig. 2. Timeline for students' collaboration in the project meeting displaying their different forms of collaborations during the meeting as seen in the main group room. Each student is colour coded making their participation in different constellations visible. The scale on the time axis is hour and minutes from the beginning of the session. Episodes are numbered in line with numbering in Bernhard, Davidsen, and Ryberg (2023).

The analysis presented in Fig. 2 clearly display that the students for a considerable extent work individually. However this individual work is interspersed with several longer and shorter collaborations in dyads and triads in shifting constellations. Some "whole group" discussions in this group of four can also be seen. Furthermore, a 10 s pause was observed between the dyad in episode 22 and the triad in episode 23. In a similar vein we usually observed pauses of 5 – 10 seconds in the interactions when students shifted from participating in one constellation to another as for example in episodes 30 – 33. Episode 11 also represent a very short, but distinct episode of individual work, between triads in episodes 10 and 12. In these short pauses the students would typically have a quick look in their computer, on a note, or to a drawing. To not clutter Fig. 2 to much we have usually not represented these, very short, pauses in the Fig.. Nevertheless, we think that these pauses are important in the interactions and for the collaborative work as they allow the students to check their drawings and notes.

3.2 Examples of different individual and collaborative constellations

In the first example we can in Fig. 1a above see the female students Ina, Heidi, Mette, and Sine working individually (episode 19) around the group's main table. Ina is trying to resolve an issue with conflicting design requirements by making drawings and trying things out with a Styrofoam model (Fig. 1b). After a while, in Fig. 1c she calls for Mette's attention. Mette, still sitting on her chair, "rolls" over to Ina's place. Here we can clearly see the initiation of a dyad between Ina and Mette both by their verbal exchange and by the embodied action in form of a physical movement of Mette to Ina's place. It can also be seen that Heidi and Sine continue to work individually.

a. 

b. 

Fig. 3. Episodes 22 and 23 – Ina and Mette (a dyad) continue their discussion from episode 20 turn to Sine (a triad) to be allowed to make adjustments.

In Fig. 3a continuation of the discussion between Ina and Mette in Fig. 1c – 1d is displayed. However, Mette have now "rolled" back to her place and Ina has walked over to Mette's place at the table. They make use of CAD, photos, and different gestures to discuss the issue at hand. In Fig. 3a it is displayed how they make use of photos of different buildings as a resource in their discussion. However, as a change might affect what Sine is working with, she is addressed by Ina in Fig. 3b. The dyad Ina-Mette (episodes 20 and 22) is changing into a triad Ina-Mette-Sine (episode 23). Heidi is still working individually. It should be noted that Ina and Mette are silent for 10 s before addressing Sine.

As is shown in Fig. 1c – 1d Mette oves over to Ina's place around the table to move back to her place in Fig. 3a. Instead Ina have in Fig. 3a moved over to Mette's place and is standing behind her. In our analysis of the video-recordings we have seen other, similar, movements among the students in their interactions. Even during the phase that followed the one hour period analyzed in this study we observed that the collaborative patterns were not “static”, but the students made “guest visits” for co-ordination purposes. Thus, we not only observed different constellations of individual and collaborative work but also observed fluidity in “spatial” constellations. In Fig. 4 we have made a “spatial” representations of the collaborations presented in Fig. 1c – 1d and 3a – 3b.

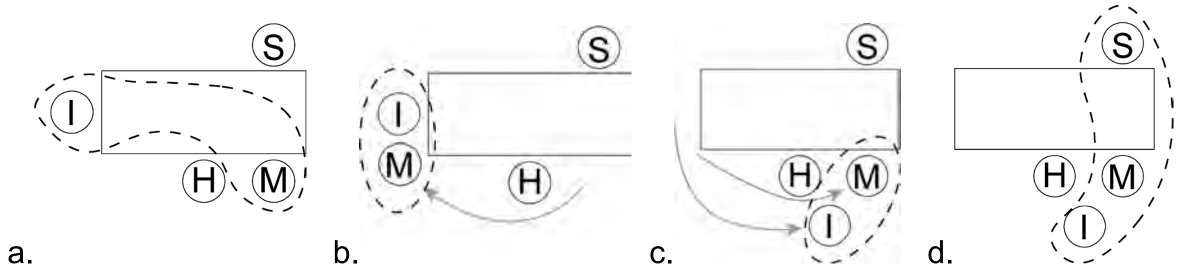


Fig. 4. Spatial representation of collaborations: a) represent the collaboration in Fig. 1c, b) represent the collaboration in Fig. 1d, c) represent the collaboration in Fig. 3a, and d) represent the collaboration in Fig. 3b. Dashed encirclements show collaborations and arrows show movements. I = Ina, S = Sine, H = Heidi, and M = Mette.

For space reasons we are not able to present more example although we have analyzed the whole, one hour, session as can be seen in Fig. 2.

4 CONCLUSION AND DISCUSSION

This study set out to answer the research question *how could we describe and understand the dynamics of students’ individual and collaborative work in the studied one hour of a design meeting?*

A limitation of this study is that we hitherto only have had time to do an in-depth study of the group practices in one collaborative design group. This somewhat limits the conclusion that can be drawn. Nevertheless, we argue that anyway several conclusions can be drawn from our findings. In the literature (e.g. Borgford-Parnell, Deibel, and Atman 2013; Menekse et al. 2017) intra group practices in static groups are reported. On the contrary we found, by analysing video-recordings, that the fine-grained patterns of students’ social interaction within the observed collaborative design group to be complex and dynamic and it display fluidity as well as structure (cf. Sørensen 2022) as the students during the day worked in many different constellations. It was observed that students often changed constellations and break into subgroups of one, two or three students to do some work and to congregate later as a whole group. Thus, we found that the patterns of collaboration in groups practical day-to-day work were not static but displayed a myriad of different patterns. To our knowledge, this study and our previous study (Bernhard, Davidsen, and Ryberg 2023) is one of the first studies to report this fluidity of constellations and to report complex collaborative patterns in students collaborative group work.

Furthermore, in line with the observation by Ryberg, Davidsen, and Hodgson (2018, 240), we also noted that the distinction between cooperative and collaborative work seem to blur when we studied students' interactions in detail as they, in their activities, alternated dynamically between individual, cooperative, and collaborative patterns of work. Thus, our results challenge a naïve individual-collaborative-binary and a naïve cooperative-collaborative distinction. Rather, the observations made in this study might imply that individual work might be an important element in constructive and skilled collaborative work.

Thus, our results points to the need to investigate group practices and individual and collaborative learning in design project groups and other collaborative learning environments in more detail. It would be important to better understand which features (e.g., collaborative patterns, skills needed by students, etc.) are important for successful learning and good collaborative work in students' collaborative design projects and how these can be fostered and developed in engineering education. We have collected a large corpus of video data from A&D-students at Aalborg University in their first, fourth and fifth semesters. Thus, we have an excellent empirical material to continue study the questions raised by this study.

For engineering education researchers to be able to make more realistic and sound pedagogical recommendations, and for engineering educators to make sound decisions, they need to have a good understanding of how students' design processes play out in reality. As already mentioned, a limitation of this study is that we hitherto only have had time to study the group practices in one collaborative design group and it limits the pedagogical recommendations we can make based on our empirical material. Still, one conclusion is that localities where collaborative work is taking place need to be designed, or adapted, for flexible group work and another tentative conclusion might be that instructors should encourage fluid collaboration patterns in students' collaborative work.

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ENGINEERING STUDENTS REFLECT ON WORK-LIFE RELEVANT LEARNING

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ABSTRACT

As engineering education is a professional education, it should prepare students for working life. However, there are obvious limitations to the amount of content that is possible to cover and the authenticity of the learning environments. In this study, we investigate the students' awareness and perception of these limitations by answering the following two research questions: *What competencies do the students view as work-life relevant? How do students reflect on their opportunities to learn these competencies?* The context of the study is the five-year Master of Science in Engineering and Computer Science at KTH Royal Institute of Technology. Throughout the programme, the students attend a programme-integrated course with

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four reflection seminars including written assignments each year. In their fourth year they wrote reflections on their perceived work-life readiness and 38 of these reflections were analysed thematically in this study. We find that students expressed an elaborate view of what constitutes work-life relevant competencies. They readily identify learning experiences in the programme where they have developed such competencies, for instance through projects. They also show an understanding that there are limitations in the ability of the university environment to achieve fully authentic learning experiences. Many students see it as their own responsibility and necessity to complement their education with other opportunities for work-life relevant learning, such as hobby projects or internships. Others seem relaxed about any gap they may have in their work-life preparation and expect to learn on their first job.

1 INTRODUCTION

1.1 Preparing Engineering Students for Working Life

Engineering is a professional education and much work in the engineering education research community focuses on work-life relevant competencies (see for instance Buckley et al. 2022; Passow and Passow 2017; Trevelyan 2007, 2010; Jonassen et al. 2006) and, consequently, how education can better prepare students for working life (Crawley et al. 2014). In engineering education programmes, educators make efforts to address the knowledge and understandings, skills and abilities, and judgements and approaches that the graduates will need in working life. Even in many theoretical courses, the relevance of concepts is explained with reference to their practical use. Some parts of the education are organised to resemble professional practice, for instance project-based learning activities (Edström and Kolmos 2014). Still, there are limitations to the authenticity that can be created within the university environment, and within the scope, resources, and confines of an educational programme. Because of these limitations, it is necessary to question to what extent students are actually prepared for working life and studying the matter empirically can provide valuable feedback to educational programmes. This is often done from the perspective of the industry (Radermacher et al., 2014), but prior research has also been studied from a faculty perspective (Magnell and Kolmos 2017; Magnell, Geschwind and Kolmos 2017). Here, the issue is instead investigated from the perspective of students. This helps us better understand how they perceive their education which is important since it does not have to correspond with the perception of the faculty or the industry.

This study also serves as a starting point for a longitudinal research project investigating the students' progression from university into working life. In this project, a group of students will be followed from the later part of their education through their first year of working life. These students will be interviewed three times, once while finishing their master's thesis, and then twice during their first year of work (cf. Brunhaver et al. 2017). At this point, however, the students who participate in this study still have one year left before graduation. Guided by the following two research questions, we analyse written reflections addressing work-life relevant competencies.

- What competencies do the students view as work-life relevant?
- How do students reflect on their opportunities to learn these competencies?

However, it can be worth noting that as with all studies investigating perceptions, the students' view of work-life relevant competencies does not necessarily align with the actual relevant competencies.

In this paper, the term competency refers to *a combination of knowledge, skills and dispositions situated in a relevant context*. This definition corresponds to the competency model presented by Frezza et al. (2018).

2 METHODOLOGY

2.1 Context and Participants

The context of the study is the five-year Computer Science and Engineering programme at KTH Royal Institute of Technology. The first three years of the programme result in a bachelor's degree and the final two years in a master's degree in computer science. The programme contains courses that are mainly technical, as well as courses or learning activities that specifically support the students in developing professional skills such as communication and project work. One such course is the *Programme Integrated Course* (PIC) which aims to strengthen the programme coherence by allowing the students to reflect on the programme design and programme progression, and by addressing relevant topics such as study technique, ethics, ergonomics, procrastination, and mental health (Kann, 2019). The five-year programme contains two longitudinal PIC courses, one that spans over the first three years, and another over the final two.

In the PIC course, students are divided into groups, mixing students from all years enrolled in the course. For instance, in the second PIC, groups consist of 16-18 students from years four and five. Each group has a mentor from the computer science faculty who remains with the group throughout the course. Each year of the PIC consists of four seminars, addressing different topics. Before the seminar, the students read some preparatory material and write a reflection of 500-1000 words. They also read and give feedback on a selection of the other students' reflections.

2.2 Data collection

In this study, we analyse reflections written for a PIC seminar on the topic "*Future of Computer Science as a Profession*". The students were instructed to write about their own work-life readiness and the computer science skills and knowledge that they believe will be important in the future. The instruction was to take both the preparatory reading (Radermacher et al. 2014; Rainie and Anderson 2017; Loui and Miller 2008; Vinuesa et al. 2020) and their own experiences from the programme into consideration. While the reading probably helped the students deepen their reflections, it likely also influenced what they brought up as relevant. Our dataset in this study is limited to reflections submitted by the fourth-year students. Of the 111 students, 38 gave voluntary consent allowing their reflections to be used in this study. This selection could potentially affect the diversity and content of the reflections.

2.3 Thematic Analysis of the Student Reflections

To answer our research questions, we have taken an inductive data-driven approach following the framework for reflexive thematic analysis by Braun and Clark (2006; 2019). The analysis was done by iterating through the data several times. We started out by familiarise ourselves with the data, by reading through the reflections while making notes in the margins. We then coded the data, initially with pen and paper before going over the reflections again using the qualitative analysis software NVivo.

Through each iteration, some of the codes changed as we started to reach a better understanding of the material. This made it easier to group the codes into themes, which was also done iteratively as we finalised the coding and discussed the results. For example, the theme *theoretical subject competencies* consisted of codes such as *fundamental CS*, *theoretical knowledge*, *algorithms* and *mathematics*. All final themes for the two research questions are presented in the results section below.

RESULTS

In this section, we present the themes from the analyses of the student reflections for each of our two research questions. Excerpts from the interviews are used to further illustrate the themes and to protect the students' anonymity we have given them gender-neutral pseudonyms.

2.4 Work-Life Relevant Competencies

In the students' discussions of work-life relevant competencies, we generated the following six overarching themes: *practical subject competencies*, *theoretical subject competencies, engineering problem-solving*, *interpersonal and personal competencies*, *authentic project-related competencies* and *adaptability and self-regulated learning.* Each theme is presented in detail below. The subject competencies in this context are related to computer science, but their nature is not unique to CS.

Practical Subject Competencies

These competencies relate to the practical aspects of the engineering major, in this case, computer science. Students bring up specific topics, such as version control and unit testing, proficiency in different programming languages, interacting with databases, cloud computing, etc. One student discussing these types of competencies was Alex, who worried they might be lacking:

> "I unfortunately find that I personally will be lacking in several of these skills when graduating. This includes areas like testing, databases, debugging and configuration management." – Alex

Theoretical Subject Competencies

In this theme, students emphasise the theoretical areas of their education. This includes mathematics and theoretical aspects of computer science, such as algorithm design, theoretical knowledge about databases, different programming paradigms etc. Many students believed these competencies to be some of the most important ones to acquire at university since they are likely to stay current and act as a foundation when learning other competencies in the future. In Robin's words:

> "I think it is more important to have the theoretical background and fundamentals than the ability to use specific software." – Robin

Engineering Problem-Solving

Engineering problem-solving was frequently brought up as a foundational and future-proof engineering skill. The students also view it as a broad competence, closely connected with several of the other themes. One student motivating the importance of the theme was Kim:

> "Problem-solving is a very broad skill that will likely always be incredibly important, as almost all work as an engineer in any field will include problem-solving." - Kim

Interpersonal and Personal Competencies

This theme contains necessary competencies that students often categorise as "professional", "soft", or "non-technical". These include communication, collaboration, creativity, critical thinking, ethical consideration, project and time management, intercultural competencies etc. Andrea motivates how proficiency in these competencies can aid work related to more technical themes:

> "Soft skills such as the ability to learn and adapt, communicate and work in a team are just as important now and will continue to be in the future. These skills ensure that the employees can apply their technical skills in a more effective and profitable way." – Andrea

Several students also provide concrete examples of when competencies from this theme are crucial. Jessie, for instance, commented:

> "And sometimes you don't even want to do what the client says they want, you need to understand why they want something, and perhaps offer a different and better solution." – Jessie

Authentic Project-Related Competencies

This is a broad theme covering the bigger picture of engineering. It focuses on how successful work in real, full-scale engineering projects requires multiple subject competencies used together. Students point out the big difference between their small homework problems or course projects and the projects that they will be part of when they enter the workforce. Such projects have more dependencies and the students might be given tasks that they rarely encountered during their education. Students brought up, for example, that they would need to be able to work with large code bases, follow industry standards, and handle production environments and deployment which they rarely, if ever, encounter during their degree.

> "I do think the ability to use different types of software and understand the big picture of things will be important." - Robin

Adaptability and Self-Regulated Learning

This theme captures competencies related to the concept of life-long learning which the students describe as crucial for work in technology since the industry changes quickly. This was one of the more frequently mentioned competencies. One of the students who stressed it was Noel:

> "One valuable skill is the ability to learn on your own, which makes it much easier to be a lifelong learner. This will make it possible to faster adapt to new advances in technology and in the field." – Noel

2.5 Opportunities to Learn the Work-Life Relevant Competencies

In this section, we present the four themes related to the second research question which addresses where and how the students think these competencies, which they had identified as work-life relevant, could and should be learned. The four themes were: *learning within the education programme*, *learning at work or internships during the education*, learning *through their own projects* and *learning at work after graduating*, and are described in detail below.

Learning within the Education Programme

The students naturally brought up their education programme as a place for developing several of the work-life relevant competencies. However, they also acknowledged challenges associated with teaching certain competencies in higher education due to both the lack of time and sufficiently authentic learning opportunities. This especially affected the *authentic project-related competencies* as well as some aspects of the *interpersonal and personal competencies* since there will be additional requirements in "real world" settings. Noel, for example, points out that although they practice aspects of communication, there are other aspects which are covered less in the programme:

> "Furthermore I probably lack skills working with customers, although I have done that in other jobs I have not done it in regards to software development. However, I feel like we practice communicating without using too much technical jargon etc." – Noel

The students also identified a number of practical subject competencies that they believed could have been taught more efficiently, for example by using more current software. However, they predominantly address the lack of progression that is caused by little focus on the necessary competencies in mandatory courses as well as the lack of assessment of these competencies. This requires the students to keep practising on their own or manage to choose the right elective courses (which can be difficult since they do not always know what is taught in the courses and what they need to focus on). Despite these issues, the students generally agreed that the role of the university was to provide a foundation consisting of *theoretical subject competencies*, *problem-solving* and *adaptability and self-regulated learning* which many claimed their education programme had succeeded with. In Charlie's words:

> "I understand that the courses mainly aim to build a foundation in the topics covered and I still think overall the learning outcomes are beneficial for the students taking the courses." – Charlie

Learning at Work or Internships during the Education

Since the lack of authentic learning opportunities was the main reason why the students believed they would not develop all necessary competencies to a satisfactory level, they naturally suggest the workplace as an additional learning environment. Several students mentioned that they either had software-related jobs on the side and/or that they had, or planned to, participate in summer internships in order to complement their degree. As mentioned by Elliot, internships can also help students experience what work-life entails:

> "Summer internships have enabled me to apply the skills I have learnt in university, deepening them while obtaining a better understanding of what is expected of me so that I can further prepare myself for life after graduation." – Elliot

Learning through their Own Projects

Another common strategy to lessen the competency gap is to pursue personal hobby projects or to participate in open-source projects. By creating their own projects, the students are also able to build portfolios which can be used to showcase both their technical skills and project planning. Additionally, open-source projects can be an opportunity to experience work in large codebases and to coordinate one's work with other developers. Noel is one of the students advocating for learning through projects and especially points out that this could be a way of learning different development tools which relate to both the *practical subject competencies* and *production competencies*.

> "I believe that my own skill gap could be fixed by […] creating projects on my own. One possibility could be to start contributing to open-source projects since that would force me to learn different development tools." – Noel

Learning at Work after Graduating

As mentioned above, many students seek opportunities for authentic learning opportunities by working on the side, participating in internships or learning on their own through hobby projects or open-source projects. However, we see that this is not applicable to everyone since they do not think that they have the time, energy or opportunity to participate in these activities. For some, their studies already take up all their time, while others have other jobs (not related to computer science) on the side and need the income. Some students express stress over this, while others were more relaxed. They were well aware that they would not be "fully trained" when graduating and some even argued that it would take years of work experience until they reach sufficient proficiency in the practical competencies, as illustrated by Alex:

> “I think there are a lot of skills that can only be obtained through practical experience in the industry, skills that also do not simply arise five months into the work-life, but skills that will require perhaps a couple of years of professional experience.” – Iliah

Some also point out that their prospective employers are aware of their need for additional training. Sasha explains:

> “There’s also a reason why companies have “junior” and “senior” developers, it’s okay to not know everything in the beginning and learn on the job. After a few years you will have learnt a lot and are hopefully ready to help the new graduates who are in the place you used to be.” – Sasha

3 DISCUSSION AND CONCLUSION

Throughout the reflections, students show insight both into what competencies are relevant for working life and how these competencies can be acquired. They acknowledge that there are limitations to the authenticity that can be achieved within the learning environment at university and that this will affect their level of proficiency in some of the competencies when graduating. They also recognise that it would be impossible to learn everything that could be useful within the timeframe of their degree and that some skills and knowledge would be outdated when they graduate anyway due to the fast pace of the industry. Because of this, they primarily see the university as a place to build a theoretical foundation in their discipline and to learn how to obtain new knowledge and skills when needed which will be crucial in their future work-life. When students reflect on their acquisition of the necessary work-related competencies, they identify three responsible stakeholders: themselves, the university and their prospective employers. Between these three, we find that they express a balanced view of their shared responsibility. The university is responsible for providing high-quality education within its limitations, and although the students in this study were overall satisfied, many also point out that there is room for improvement. Since the university is not able to provide a fully authentic learning environment, the students argue that part of the responsibility has to be placed on their prospective employers to continue providing opportunities for learning and training when they start working. They also point out that there are a vast number of different branches and software within computer science which could be relevant when working at a company, making it impossible for them to be proficient in everything and able to execute all necessary work tasks. This further motivates why their employers will have to accommodate continued learning and training. Finally, many students recognise that they themselves have to take responsibility for their acquisition of some competencies to complement their university studies. They seem to accept their own responsibility and show awareness of a wide set of opportunities for learning.

They see opportunities for learning on their own, for instance through hobbies or open-source projects, or through work or internships in parallel with their degree. This can however be difficult for some students, either due to economic reasons or time and energy limitations. Some state that they are unable to do anything extra beyond their studies.

As mentioned previously, this study does have limitations. The data consists of student reflections which were guided and influenced by preparatory reading. However, the students related the reading to their own experiences in the programme and many students also disagreed with the reading. Further, the students knew that their reflections would be read and commented on by their peers and mentor, hence it is possible that they may have underplayed their insecurities. The voluntary selection of students may have additionally increased the bias in favour of students who were proud of their assignments and felt that they displayed maturity. In the future longitudinal part of the study when we interview a sample of these students, it is possible that we may get to hear some more vulnerable views.

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BETWEEN FLEXIBILITY AND RELATIVISM: HOW STUDENTS DEAL WITH UNCERTAINTY IN SUSTAINABILITY CHALLENGES

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ABSTRACT

Universities open their doors to society, inviting the complexity of the world to enter engineering education through challenge-based courses. While working on complex issues, engineering students learn to deal with different kinds of uncertainty: uncertainty about the dynamics of a real-world challenge, the knowledge gaps in the problem, or the conflicting perspectives amongst the people involved. Although we know from previous research that students are likely to encounter these uncertainties in sustainability challenges, which metacognitive strategies they use to deal with them is unclear.

We interviewed nine MSc students at the end of a challenge-based course at a Dutch university of technology. We asked the students how they dealt with uncertainty in collaboration with the commissioner, their student team, and the teachers. The interviews were analyzed through grounded, consensus-based coding by two researchers.

Preliminary results show students use three main strategies. First, the different perspectives from peers in their team inform the position of the student. Second, students find expectation management of the commissioner essential, yet students struggle with how to do this in a professional and timely way. Third, students frame the uncertainties they encounter as part of the learning process, which allows them to accept the possibility of failure.

This study provides first insights in metacognitive uncertainty strategies and suggests those strategies should become a more prominent topic in coaching students. When uncertainty becomes an explicit part of challenge-based education, students learn to deal with both the known and unknown in the transition to a sustainable society.

1 INTRODUCTION

Much of the future of engineering eduction lies in the ability of universities to respond to the sustainability challenges of the world (Sterling 2004). Although society has increasingly been aware of the dangers of global warming and the human contribution to it since the 1970s, the impact of sustainability on education is being described by scholars only since the start of this century. In the past two decades, the idea that higher education needs to change significantly to become sustainable has led to the investigation of new pedagogies and competencies for sustainable development (Thomas 2010).

The ability to deal with uncertainty is one of the competences in sustainable education that contributes to the development of new pedagogies (Ingold et al. 2018). The complexity of sustainablity challenges fosters three different kinds of uncertainty: the dynamics of a real-world challenge, the knowledge gaps in the problem, or the conflicting perspectives amongst the people involved (Brugnach et al. 2008). Those uncertainties and the strategies to deal with them are difficult to discuss or model in lectures, case-studies, or essays, they require students to gain experience with the complexity of problems outside of the conventional learning environment (Wehrmann and Van den Bogaard 2019). Pedagogies such as challenge-based learning (CBL) allow students to practice with the uncertainties of open-ended sustainability challenges in real-life (Gallagher and Savage 2020).

Strong teacher guidance is crucial to the success of learning to deal with uncertainty in CBL. Because CBL relies on the self-directed learning of students, teachers scaffold the skills students need in the process of problem solving (Doulougeri et al. 2022). Previous research shows that if this is not done properly, these kind of problem-based learning environments have the risk of failing (Kirschner, Sweller, and Clark 2006). To provide guidance on uncertainty strategies, teachers require insights on how students recognize and approach uncertainty in CBL courses.

Although we know from previous research that students are likely to encounter uncertainties in CBL, which strategies they use to deal with them is unclear. In other words, we know *what* students are learning, but we do not know *how* they learn it. For teachers to be able to guide the complex process of learning in sustainability challenges, we need a better understanding of how students deal with uncertainty in challenge-based courses (Kirschner, Sweller, and Clark 2006).

In this qualitative study, we investigate the question: What uncertainties do students encounter when working on sustainability challenges and how do they deal with them? We interview nine MSc students at the end of a challenge-based course at a Dutch university of technology. The research is embedded in the theory of metacognition, which we shortly introduce in the next section (2). In section 3, we explain the analysis and coding process of the interviews. The results in section 4 first present the uncertainties students talk about in the interviews and then the three groups of strategies we found they use to deal with them. Finally, we discuss what the implications of this study on uncertainty are for the development of engineering education and sustainability education in the future.

2 THEORETICAL BACKGROUND

Sustainable education is not just about the accumulation of new knowledge, but also about the process of learning (Thomas 2010). Such knowledge about learning processes or, in other words, the awareness and control of one’s own thinking is called ‘metacognition’ (Flavell 1979). Metacognition is a large field of study encompassing psychology and behavioral, learning, and cognitive sciences and our short discussion of the theoretical background here only offers a small glance at the literature.

Metacognition consists of two distinct, but connected elements: (1) the awareness and knowledge of the self and (2) the conscious control and regulation of cognition. Self-directed learning strategies, such as organizing information or asking help from peers, are metacognitive ways to control the process of thinking (Zimmerman 1989).

Uncertainty arises from what we do not know, whether this is because knowledge is not available, contested, or unpredictable (Brugnach et al. 2008). Therefore, to be able to recognize uncertainty, students need to be aware of the limits of their own knowledge. This requires at least the first element of metacognition: awareness of one's own knowledge. Then, to deal with uncertainty students need to be able to self-regulate their learning, while taking into account what they do not know. To the best of our knowledge, a study investigating specific metacognitive strategies to deal with uncertainty in sustainable education has not been done before.

3 METHODOLOGY

3.1 Case study

We researched student experiences on uncertainty in a challenge-based course for urban sustainability at a university of technology. The 24 ECTS course is part of a two-year MSc program in the Netherlands. In the course, students work in groups of four or five students on a real-life challenge in urban sustainability. Each team is guided by both a coach from university, who offers academic expertise and assesses the students' work, and a commissioner from practice, who is providing the case.

3.2 Data collection and analysis

We conducted in-depth, semi-structured interviews with nine students, each from a different team. The students were selected by an open call amongst all student teams to participate in the research voluntarily. We analysed the answers to the question 'how did you deal with uncertainty during the course?' and the answers to the clarifying questions the researcher asked during the interview.

Two researchers coded the answers in a consensus-based coding process. In the first cycle of coding, the first author created the code book through open coding with 30 codes from 75 quotations. The second researcher used this code book for the second cycle of coding and added 8 codes. Those 38 codes were grouped in two categories: uncertainties (the things students found to be uncertain) and strategies (what they did to deal with those uncertainties). Quotations could have multiple codes, if, for instance, an uncertainty and a strategy to deal with that uncertainty were mentioned in the same sentence. Because of the small group of students in this study, we only present the codes that were mentioned by more than one student.

Table 1. Overview of the codes that were mentioned by more than two students in the interviews.

Code group	Code	Description
Uncertainties	Changes during the project	Through new insights during the project, the student would have made other decisions when looking back.
	Conflict commissioner	Challenges, tensions, or conflicts that arise from working with the commissioner.
	Unclarity assignment	Unclartiy about the expectations of assignments.
	Usefulness results	Uncertainty about the quality of the outcome and the usefulness for practice.
	Lack of knowledge	Student was unable to find certain answers or information.
	Expectations	Students are confronted with their own expectations of the course turning out different in reality.

	Unclarity roles	Searching for the position of the student or student team in collaboration with others.
Strategies	Attitude	Student describes dealing with uncertainty as a specific attitude towards not knowing (embracing uncertainty).
	Conversations commissioner	Talking to the commissioner about uncertainty (for instance in roles or differences in expectations).
	Conversations coach	Talking to the coache about uncertainty (for instance to clarify assignments).
	Conversations team	Discussing challenges with other team members to resolve them or get a better understanding of them.
	Acceptance of conflict	Accept that conflict can be part of the process.
	Learning process	Framing the uncertainties or challenges as a valuable part of the learning process.
	Persistency	Stick to the plan and convincing others of this direction.
	Understanding other perspectives	Empathy towards others that might have caused uncertainty.
	Acceptance of failure	Accept that certain knowledge is not available.
	Relativism	Student describes embracing or accepting the not knowing.
	Taking a break	Going home early or taking a walk.

4 RESULTS

4.1 Uncertainties

In the interviews, we found sixteen different uncertainties, seven of which were mentioned by more than one student (Fig. 1). The most often mentioned uncertainty was ‘changes during the project’ (7 times). As new insights arose while working on the challenges, it caused students to rethink their previous steps. Student 1 said:

> ‘If we had known beforehand that the commerical applicability of wood would not have been wortwhile to research, I think we would have focused much more on the reuse of material within the municipality. Because the entire financial motive [to research this] fell away.’ [1:16]

In this context, two students said they believed unpredictability was an inherent part of doing research. For example, student 6 said:

> ‘I know that it is alright not to know what direction the research is going, for whatever reason.’ [5:2]

The second most mentioned uncertainty students experience was about conflict with the commissioner (6 times). Also codes such as ‘unclarity roles’ and ‘expectations’ refer to uncertainty in collaboration with the partner from outside of the university. Especially at the start of the course, students said they struggled with managing the expectations of the commissioner and giving direction to the research.

Furthermore, students experienced uncertainty in the usefulness of the results for the commissioner (4 times). The applicability of the results in practice was an important goal to some of the students. Student 1:

> ‘In my case, the uncertainty was mostly the quality of the data and the applicability of the results.’ [1:1]

When students mentioned that the assignment was unclear (5 times), they talked about different assignments in the course. Student 7 said to experience stress because of unclarity on the assignments in all stages of the project.

> 'At the start, we did not know what we had to do. In between, the uncertainty was about what we were going to make for the commissioner. At the end, we had difficulty deciding what to write down in the report.' [6:3]

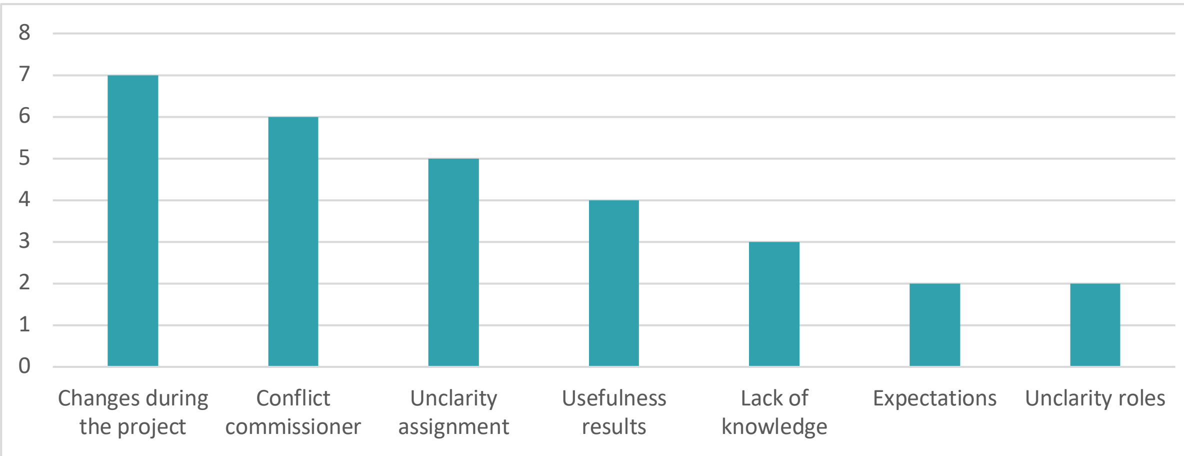

Fig. 1. Bar chart showing how often students mentioned specific uncertainties in the interviews.

4.2 Metacognitive strategies

Within the 22 coded strategies (Fig. 2), we found three groups: talking about uncertainty, developing a specific attitude to deal with uncertainty, and practical strategies for managing uncertainty.

First, the most prominent strategy to deal with uncertainty for the interviewed students was to talk about it, whether this was in conversations with the commissioner (6 times), coach (6 times), or their team members (5 times). Different uncertainties were resolved in those discussions. In conversations with the commissioner, students talked about the unclarity of roles in the process or managed expectations about the results. In conversations with the coach, students sought clarity on the assignments and avise on how to deal with their role and the role of the commissioner in the process. The conversations in the team were also about all these relational uncertainties, bus at the same time students also discussed uncertainties arising from tasks. Student 4, for example, said:

> 'Especially from the moment we divided the tasks, if it was unclear to one of use how to proceed, we discussed together.' [4:4]

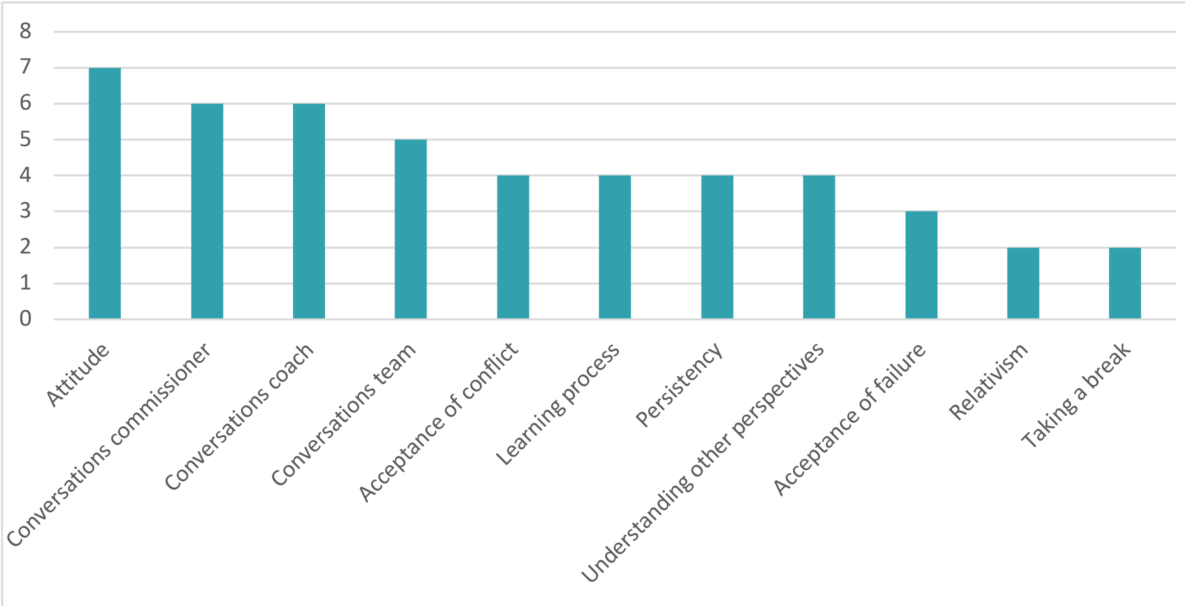

Fig. 2. Bar chart showing how often specific strategies to deal with uncertainty were mentioned by the students in the interviews.

Furthermore, students talk about their attitude towards uncertainty (7 times) as a way to deal with uncerainty. Student 3 said about embracing uncertainty:

> '[…] so part of dealing with it [the uncertainty] was also kind of letting go of the idea that you needed to know stuff before you could move on, or you could decide to just kind of accept it.' [9:2]

Similar to student 3, several students mention acceptance specifically as part of their strategy to deal with uncertainty, for instance, accepting the possibility of failure (3 times) or accepting that conflict is part of the process too (4 times). Two students said that failure or conflict were part of the learning process in the course. Another attitude towards uncertainty we found was 'relativism' (2 times), when a student doubts to what extent the world is knowable. Student 1 said:

> 'I'm quick in thinking, I don't know things, than all of it is nonsens.' [1:11]

One student described how the change in attitude led to different actions in the project:

> 'If you do not know the answer to something, you find a way to accept this and deal with it and find a different way to approach the problem.' [5:1]

Four times 'persistency' was mentioned as an attitude towards uncertainty. Those students describe how they tried to persuade others of their story, solution, or interpretation of the problem.

Finally, students mention several practical strategies to deal with uncertainty, such as taking a break (2 times) when feeling stuck or to ask for feedback (1 time). One student said to make use of examples of the reports from last year in the course to deal with the unclarity of the assignment. Such metacognitive strategies are often related to uncertainty in specific tasks.

5 DISCUSSION AND CONCLUSION

5.1 Discussion

The unpredictability in sustainability challenges is one of the most common uncertainties to the students we interviewed. Brugnach et al. (2008) ascribe this to the complexity of the societal transitions that sometimes show non-linear and chaotic behavior. For them, accepting these dynamics as they are and embrace the notion that their unpredictability will not change in the foreseeable future is the way to deal with this kind of uncertainty. Attitudes accepting conflict and failure that the students in our study adopted correspond with this, yet were not the only attitudes students fostered towards uncertainty.

Students' attitudes towards uncertainty not only seem to be highly individual and personal, but also depending on the kind of uncertainty they are confronted with. Dealing with a lack of knowledge, because, for instance, data or people were not accessible, could lead to students responding with the flexibility to seek other approaches to achieve their goals or relativism, where students lost some of their confidence of what they were doing was still going to succeed.

'Seeking social assistance' is one of the self-regulated learning strategies defined by Zimmerman (1989) that is clearly recognizable in the results from our study as 'conversations with commissioner, coach, and peers'. At the same time, students perceive the collaboration with a commissioner as a source of uncertainty related to 'multiple knowledge frames' (Brugnach et al. 2008). The coach is only mentioned in relation to seeking strategies to deal with uncertainty but not a source of uncertainty itself. This shows that different roles within CBL also have a different function in the learning process.

Several authors have found explicit teaching of metacognition to be effective (Perry, Lundie, and Golder 2018; Muteti et al. 2021). Additionally, the instruction of teachers becomes more effective when those teachers are aware of the learning strategies of students (Newell et al. 2004). Therefore, metacognition in sustainable education seems to be a key area for further investigation in order for teachers to guide the process of choosing the right strategies.

5.2 Limitations and suggestions for future research

This study is limited by its explorative and qualitative character. The in-depth interviews that form the heart of the methodology are necessary to get to difficult to measure concepts such as uncertainty and attitude. However, the conclusions presented here should be seen in the context of a single case study in a graduate (MSc) programme, where students are relatively academically mature. Such an in-depth qualitative study with only nine students prepares qualitative and quantitative research on a larger scale. That research is necessary to present the metacognitive strategies we found with more clarity. Furthermore, research on how to explicitly teach metacognitive strategies could offer support to teachers in their changing role as coach in CBL courses.

5.3 Conclusion

This study provides first insights in metacognitive uncertainty strategies used by students in challenge-based education. In nine in-depth interviews, we asked students which uncertainties they experienced in the sustainability challenge they worked on and how they dealt with those uncertainties.

The results show students use three main strategies. First, conversations with commissioners, coach, and their team members allow students to gain a better understanding of the uncertainty. Second, students develop different attitudes towards not knowing. Third, students use practical strategies, such as taking a break or asking for feedback, to deal with uncertainties related to specific tasks.

Although this study is small scale and more research is necessary to get a better understanding of uncertainty in the context of CBL, it underscores the importance of conversations between commissioners, coaches, and students as part of the learning process. Furthermore, the implications for engineering education based on this study are that dealing with uncertainty helps to grow selfawarenes and are very much dependend on the self-regulated learning strategies students employ. Ultimately, selfknowledge allows students to critically reflect on what they know, on what they don’t know and, most importantly, on what they can know. It is the task of this generation of students to anticipate what knowledge is needed to make strategic next steps towards a sustainable society.

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A LOOK INSIDE THE ENGINEERING STUDENTS' BACKPACK.
DIFFERENCES IN ENGINEERING CAPITAL ACCORDING TO GENDER OR MIGRATION BACKGROUND

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ABSTRACT

Every student has a unique combination of experiences, resources and social networks related to engineering, called ‘engineering capital’, derived from Archer’s concept of ‘science capital’. The engineering capital gathered throughout life creates a backpack that impacts someone’s aspirations to study engineering, as well as the performance and persistence in the programme itself.

Engineering technology is one of the most homogeneous fields within the STEM domain, being mostly white and male. To stimulate a more diverse engineering technology field, this research paper investigates the relationship between the level of engineering capital and gender or migration background, as well as the influence of engineering capital on aspiration and performance within the engineering technology field.

Through an online survey, last-year secondary education pupils in math/science tracks (N = 490, March 2023), and first-year engineering technology students (N =391, October 2022) in Belgium were asked about their engineering capital, and engineering aspiration (pupils) or performance (students). Results disclose little difference in engineering capital, engineering aspiration, or engineering performance for students with a migration background. However, female pupils appear to have less engineering capital than male pupils, and in need of more engineering capital to gain an interest in engineering technology compared to male pupils. Once women start the engineering technology program, engineering capital does not influence female students’ performance differently than male students. It is possible that only those with a heavy backpack of engineering capital find their way to the program. That is why it is important that educators stimulate students’ engineering capital.

1. INTRODUCTION

Two of the challenges faced by the engineering field are a shortage of engineers and a lack of diversity among engineers. Tackling the diversity problem can help solve the shortage of engineers by tapping into a bigger pool of talent. Diversity is not only important to attain more qualified engineers and prevent a loss of talent, it also enhances the work quality, enabling the industry to thrive. The more diverse the field, the more diverse the perspective, experiences and knowledge that are represented, which makes it easier to cater to the needs of the whole population (Page 2019).

In many countries, we see a recurrent pattern of the engineering field lacking women and people from non-dominant cultural background (Charles and Bradley 2009). Understanding why STEM-interested students do not enter the engineering field and why some groups struggle more than others during engineering education programs is essential to promote more diversity in the profession.

The concept of ‘*science capital’* is one element to understanding this problem (Louise Archer et al. 2015; Moote et al. 2021). Children and adolescents who have access to a strong science capital, through science support, knowledge, and attitudes, have a higher chance of achieving a science degree (Louise Archer et al. 2012; Aschbacher, Li, and Roth 2010). Science capital is often intertwined with other forms of capital, such as social or cultural capital. As a result, it can perpetuate the reproduction of privilege, or contribute to vulnerability (Moote et al. 2021).

This paper shifts the focus from science to engineering, by seeking an answer to the following research questions: RQ1 ‘does the level of engineering capital varies according to gender or migration background?’; RQ2a ‘does the level of engineering capital influence aspiration and performance within the engineering field?’; And RQ2b ‘does the relationship between engineering capital and engineering aspiration/performance change according to gender or migration background?’.

2. THEORETICAL FRAMEWORK: THE CONCEPT OF ‘CAPITAL’

2.1. Cultural and Social Capital

Bourdieu expanded the theory on social reproduction beyond the economic factor by including other forms of capital. He argued that social, cultural, and symbolic capital were vital to the transfer of societal power from generation to generation (Bourdieu 1986). In this paper we will focus on the first two: (1) *Cultural capital* refers to subtle, unwritten rules, values and knowledge structuring the social world. Access to cultural capital comes from both material (e.g., books, music instruments) and immaterial things (e.g., learning a new language, visiting a museum). (2) *Social capital* represents the network that surrounds someone, such as family, teachers, or friendships (Bourdieu 1986).

How capital is distributed and valued is determined within a certain social context, which Bourdieu called *field*. It is the social space in which an individual acquires capital and develops a habitus (Bourdieu 1986). *The habitus* can be seen as embodied capital that is shaped by socialization and influenced by individual characteristics like gender or ethnicity (Nash 1990).

A unique set of experiences shape how individuals interpret the world around them and outlines what seems possible and/or desirable, guiding behaviour, actions, and choices (Bourdieu 1986; Nash 1990), e.g., an educational trajectory. Bourdieu defines educational success in relation to the cultural capital that was previously invested by the family, i.e., social capital. Of course not only the level of capital is important, but also the precise content. Educational systems are often based on the dominant culture in society, which means that capital gained at home through conversations and experiences is perpetuated in the classroom. Children who’s capital and habitus are in line with the dominant culture in society will be viewed as smarter and more accomplished by others, and will navigate and flourish more easily in that society. While children who embodied a different habitus compared to the dominant culture will have more trouble fitting in (Nash 1990; Bourdieu 1986; Martin, Simmons, and Yu 2013).

2.2. ScieNce Capital

By looking at science education with a Bordieusian lens, Archer et al. (2012) learned how science-related capital, i.e., *science capital*, influences science aspiration, participation and performance. Science capital represents the backpack that people carry, filled with both social and cultural capital related to science (Louise Archer et al. 2015). Having access to parents’ knowledge, encouragement from teachers, and own experiences with science can help to prevent struggling in school, and develop a strong science identity, which will improve the ability to persist, even when struggling (Gonsalves et al. 2021).

To measure science capital, Archer et al. (2015) focused on three theoretical aspects, namely: habitus (their science attitudes), social capital (parents, teachers, conversations, etc.), and cultural capital (media consumptions, science-related activities, etc.).

2.2.1. Engineering capital

While having an extensive impact on society, engineering is one of the most homogenous fields across several countries (Charles and Bradley 2009). To improve the engineering aspiration and/or persistence of a more diverse group, we need to understand what influences engineering attitudes.

Research from Moote et al. (2020) showed that science capital was correlated with engineering attitudes (0.423), however, not as much as with science attitudes (0.779). To gain a better understanding of capital that is more focused on engineering, the focus is shirted from science capital towards engineering capital, by altering the questions about ‘science’ to ‘STEM’ or ‘engineering’, depending on the context.

2.3. The reproduction of social privilege

If having more science capital can make it easier to earn a degree in a science field, it is prevalent that those who have less science capital, will have more difficulty to get there. When looking at the often homogenous groups of STEM students being from a middle or high class family, often white, and male (depending on the field), we can wonder why this homogeneity prevails (Moote et al. 2021).

Students from a long-term educated family, especially in a science field, have more chance to build science capital, and are therefore often overrepresented in science education (Dorie et al. 2014). People with a migration background more often belong to a shorter term educated families, resulting in lower level of science capital that is in line with the dominant culture. Even when they have a lot of interest and talent for science, they will be less likely to see themselves as a scientist, let alone choose or persist in a scientific domain (DeWitt et al. 2011; Aschbacher, Li, and Roth 2010; Gonsalves et al. 2021).

The same goes for women, who less frequently pursue a science degree compared to men (Moote et al. 2021). In Western society, science is associated with cleverness and masculinity (Louise Archer et al. 2020). From the age of 6, girls already perceive their own intelligence lower than the intelligence of boys, leading them to pursue less activities connected with cleverness (Bian, Leslie, and Cimpian 2017), science or engineering being one of these. Not only do they underestimate their own intelligence, the general bias of science and STEM being for boys, lead to more encouragement for boys from their surroundings and results in less science capitals for girls. The girls who do find their way to STEM often need a stronger conviction, or habitus, wanting to study science and go against the grain of what society (unconsciously) expects from them (Louise Archer et al. 2020; Aschbacher, Li, and Roth 2010).

When children or adolescents do not have access to science capital through their parents or resources at home, school becomes an important source of science capital. Educators in secondary school, but also at the university, can give guidance, support, and encouragement when needed (Martin, Simmons, and Yu 2013). When it comes to engineering, it is difficult to know what skills or preparations are needed for a degree in engineering, especially when parents are not familiar with what engineering is, or even with the university system. Educators play a crucial role in guiding students towards their desired path (Dorie et al. 2014; Martin, Simmons, and Yu 2013).

3. METHODOLOGY

3.1. Participants

This study is based on two surveys. The first was conducted in October 2022 (N=343 after cleaning; 36 female; 20 with a migration background) among first-time engineering technology students at KU Leuven, Belgium. First-time students are first-year students who enrol right after completing high school. The students who wanted to participate had the opportunity to voluntarily fill in the survey during one of their classes. Later in this paper we will refer to the results from the bachelor of engineering technology with ‘ET’.

The second survey was conducted in March 2023 (N=443 after cleaning, 203 female; 58 with a migration background) with last-year pupils in science or math tracks, across ten secondary education schools. The pupils voluntarily completed the survey during class, or during a free moment, except for two schools where the pupils could conduct the survey online at home. Later in this paper we will refer to the results from secondary education with ‘SE’.

3.2. Analysis

After conducting a descriptive analysis of the data using boxplots or comparison of means, a multiple regression analysis was performed. When comparing means, in the form of a table or boxplot, the Wilcoxon test with Holm adjusted p-value was used to identify significant differences. The aim of the regression analysis is to examine the relationship between sex and migration background as independent variables, engineering technology aspiration (SE) and performance (ET) as dependent variables, and engineering capital as both dependent and independent variable. Section 3.3 explains how these variables are defined and measured. Additional independent variables are added to the model as control variables depending on the target group, namely: secondary education study field (SE), parents education level (SE & ET), and language spoken at home (ET). However, we will not focus on the control variables in this paper.

When talking about a determination coefficient, the given number will always represent the adjusted R^2. Due to lack of space, the full regression tables are not included in the paper, but are available upon request.

3.3. Concepts:

3.3.1. Independent variables

The university database was used to enrich the ET dataset with demographical variables. The same logic is applied to question the SE pupils about their demographical background. A short explanation per variable is found below.

Gender/Sex: Measured by the sex on someone’s passport (ET) or their self-reported sex (SE). This means that we do not have any data on someone’s gender identity, although it must be noted that, in Belgium, it is possible to change the registered sex from the age of 16.

The term ‘gender’ is used when referring to the literature and research questions, since this is more commonly used.

Migration background (MB): Following university guidelines, respondents are considered to have a migration background when they themselves, one of their parents or at least two grandparents, are not born in with a Western-European nationality[2]

Engineering capital: Question from Archer’s et al. (2015) scale to measure the concept of science capital were translated to Dutch and altered to focus more on STEM of engineering. The scale consists of preferences, practices, and social connections, related to STEM or engineering. Every question was weighted according

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[2] List of Western-European nationalities used by the university: Belgian, British, Danish, German, Finnish, French, Irish, Icelandic, Liechtenstein, Luxembourg, Dutch, Norwegian, Austrian, Swedish, and Swiss nationality

to their theoretical significance (e.g., having a parent as an engineering has more impact than having an aunt as an engineer) and given a score ranging from 1 to 5 (Moote et al. 2020). The total sum was rescaled to a scale of 0 to 60.

Control variables: Education level of the parents; form of education; field of study in secondary education (only for SE); language spoken at home (only for TE).

3.3.2. Dependent variables

Engineering aspiration: Last year pupils were asked about their interest in studying engineering technology on a 5-point Likert scale.

Engineering performance: The students Grade Point Average (GPA), measured in percentages (0-100), is used to address the student's performance. In this paper, the GPA of January 2023 were analysed.

4. RESULTS: A LOOK INSIDE THE (FUTURE) ENGINEERING STUDENTS BACKPACK

4.1. Distribution of engineering capital

4.1.1. Boxplots

Secondary education (SE)

The boxplots in figures 3 and 4 show the engineering capital in SE and gives an insight in how engineering capital is distributed according to sex and MB. In figure 3 we see that female pupils have a significantly lower engineering capital compared to male pupils. The minimum and maximum for the female pupils is also lower than this of the male pupils.

For MB, the median of the category non-MB is slightly lower than the category MB, however, the Wilcox test does not show any significant differences.

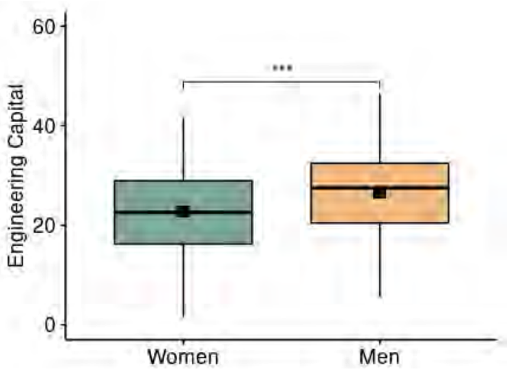

Figure 3: Boxplot of engineering capital in secondary education according to sex

**** p<.001*

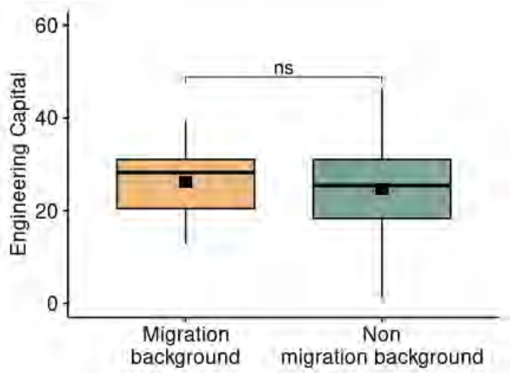

Figure 4: Boxplot of engineering capital secondary education according to migration background

Engineering Technology (ET)

The results of the ET students indicate that male students have a slightly higher median and more variance in their group than female students. Students without a MB also score higher compared to students with a MB. However, both comparisons are not significant.

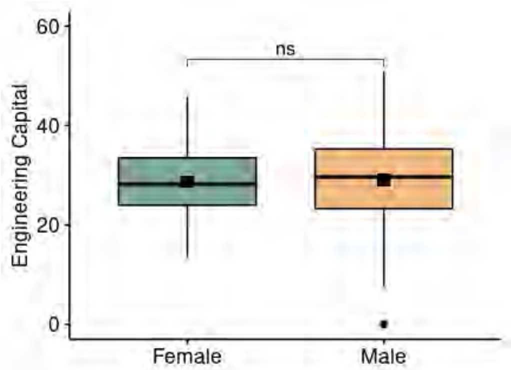

Figure 5: Boxplot of engineering capital in Engineering Technology according to sex

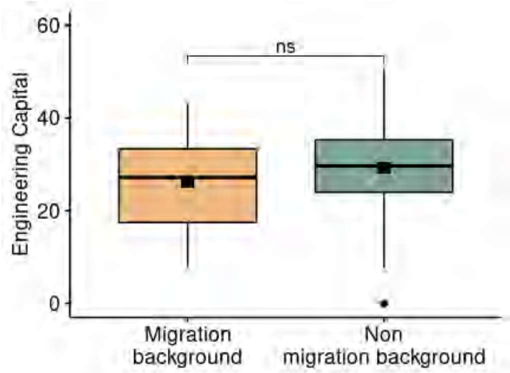

Figure 6: Boxplot of engineering capital in Engineering Technology according to migration background

4.1.2. Linear regression analysis

Secondary education (SE)

The regression models show the impact of the demographic variables on the engineering capital. The results indicate that female pupils have a significantly lower level of engineering capital compared to male pupils by 3.01 points, or 2.92 when controlling for the other variables. Pupils with a MB, however, did not show any significant impact on the engineering capital compared to pupil without a MB.

It is important to note that when looking at the determination coefficient, the model including sex and MB has an explanation value of 2.7%, which is mostly due to sex. The model with all the control variable has an explanation value of 9.7%, hence, pupil's study field and the education level of their parents probably have a bigger influence on their engineering capital.

Engineering Technology (ET)

When analysing results for ET, no significant effects are observed. Even when adding all control variables, the determination coefficient (adj. R^2=.009) shows that the independent variables added to the models are not explaining the variance in the level of engineering capital effectively.

4.2. Engineering aspirations in SE

4.2.1. Comparison of means

Since interest in ET is measured using one scale, we analyse mean scores instead of a boxplot. Male pupils appear to have a significant higher interest in engineering technology compared to female pupils. Pupils with a MB have a slightly higher interest in engineering technology compared to pupils without a MB.

Table 1: Interest in engineering technology means, st.dev., and Wilcox test results

SE		*Mean - interest Engineering Technology*	*Standard deviation*
Sex	Female	1.86***	0.98
	Male	2.98***	1.29
Migration background	No MB	2.41*	1.29
	MB	2.84*	1.25

p<0.05*; p<0.01**; p<0.001***

4.2.2. Linear regression analysis

The linear regression models show a significant effect for female pupils, where they have a lower interest in engineering technology than male pupils. This effect is weakened by adding engineering capital to the model (from β = -1.13; to β = -0.96).

Engineering capital also has a significant effect on the interest in engineering technology. For every point increase in the level of engineering capital, the interest in engineering technology increases with 0.07. No significant result was observed for students with a MB.

Interestingly, a significant interaction effect was observed between engineering capital and sex (β = -0.03), meaning that their combined effects are greater than their sum of parts. The main effect for sex did not remain significant after adding the interaction effect, while the main effect for engineering capital did remain significant (β = 0.07). This indicates that sex moderates the relationship between engineering capital and engineering aspiration.

The determination coefficient for the model looking at sex (adj. R^2 = 0.19) or engineering capital (β = 0.18) have a variance explanation of almost 20%. The last model where the control variables have been included has a variance explanation of 30%. When adding the interaction effect this is increased to 31%, indicating a slightly larger proportion of the variance in engineering aspiration being explained.

4.3. Engineering performance in ET

4.3.1. Boxplots

For engineering performances, male and female students performed similarly, while students without a MB score higher compared to students with a MB. However, there are no significant differences.

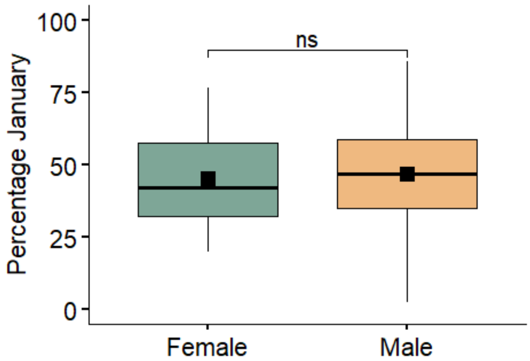

Figure 7: Boxplot of engineering performance in Engineering Technology according to sex

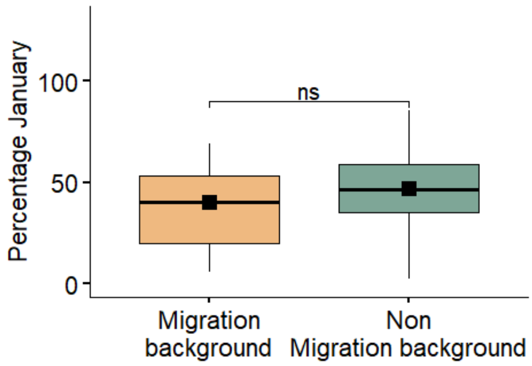

Figure 8: Boxplot of engineering performance in Engineering Technology according to MB

4.3.2. Linear regression analysis

The linear regression models of the GPA of engineering technology students do not show any significant effects for sex or MB on their GPA. However, engineering capital does have a significant effect. For every point increase in engineering capital, there is an increase of 0.43 on the GPA. This effect stays similarly when controlling for the other variables. Nevertheless, the variables added in the model seem inadequate to predict engineering performance, since the variance explanation is only 1.9%.

5. DISCUSSION AND CONCLUSION

This paper sought to investigate the relationship between engineering capital and sex or migration background, as well as between engineering capital and engineering technology aspiration in secondary education (SE) or performance in engineering technology (ET).

To answer the first research question '*does the level of engineering capital varies according to gender or migration background?*', it is important to make a distinction between secondary education and higher education. While there were no significant results for ET students, results for pupils in SE showed a difference in engineering capital based on sex, where female pupils had a lower engineering capital compared to male pupils. However, the regression model showed that sex explained only 4,4% of the variance in pupils engineering capital.

For the second research questions '*does the level of engineering capital influence aspiration and performance within the engineering field?'* And *'does the relationship between engineering capital and engineering aspiration/performance change according to gender or migration background?*' we can conclude that engineering capital does influence both engineering aspiration and performance, but that it is not always moderated by sex or migration background. The level of engineering capital has a significant positive effect on engineering performance, but this effect is not moderated by sex or migration background. Engineering aspiration is also positively and significantly influenced by engineering capital. However, an interaction effect showed that this relationship is moderated by sex, where female pupils need more engineering capital compared to male pupils to develop an interest in engineering capital.

We can conclude that female pupils have a lower engineering capital compared to male pupils and need more to gain engineering aspiration. This helps to explain that only a small group of women chooses to study engineering technology. Possibly due to the fact that only women with enough engineering capital choose to study engineering technology (see RQ1), there are no differences in performance between men and women once they enter the program. Unfortunately, we did not find enough significant results for the pupils and students with a migration background to form any conclusions.

Following the literature, a stronger connection between engineering capital and engineering performance was expected. Literature shows that engineering, or science, capital increases the chance of success in engineering education programs (Zhang 2021; Moote et al. 2021), which was only slightly visible in this study. For engineering aspiration, a clear connection with engineering capital was observed, including a moderation of the respondents sex This is in line with the literature that says that women need a stronger conviction to study engineering than men (Aschbacher, Li, and Roth 2010; L. Archer et al. 2020).

These conclusions need to be considered with precaution, due to the small numbers in our target groups. A difficulty that pops up when doing quantitative research on underrepresented groups. It would be opportune to address this matter further in qualitative research to get a better understanding of how engineering capital influences students. This approach could also give room for a focus on intersectionality between several characteristics, such as women with a migration background, for which the groups were too small in this study.

When wanting to improve the diversity in engineering programs, it is important to also focus on the pupils that were not blessed with a heavy backpack full of engineering capital and to make sure to support them and stimulate their engineering capital once they do find their way to the engineering program. Educators can take up the role of improving science capital for a diverse group of students in the form of teaching, museum visits, but also support and encouragement.

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PRELIMINARY MAPPING OF BACHELORS' RESEARCH TO ENHANCE DIGITAL CONSTRUCTION IN IRELAND

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ABSTRACT

This paper presents preliminary analyses to assess the content of student research conducted through a digital construction course offered to engineers and built environment professionals in Ireland since 2020. The course aims to upskill employed, mature students with a one-year intensive study period in Building Information Modelling (BIM/Digital Construction), and ultimately enable them to earn an honors-level Bachelor of Science degree. Obtaining this degree requires the student to produce a research dissertation, and the course helps students use research and research-thinking to answer pressing questions they encounter in the

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Architecture, Engineering, and Construction (AEC) context. The paper briefly discusses context of Technological University Dublin's BIM courses, the rationale behind offering these courses, and how they address the shortage of BIM knowledge in Ireland. Work reported in this paper involved the collection of the full text of all BIM BSc dissertations and preliminary, systematic content mapping—using titles and keywords provided by the student authors—to identify themes across the body of 59 BIM BSc dissertations submitted to date. This foundation will support subsequent work to assess the quality and usefulness of research from the BSc as well as MSc BIM courses, and BIM research published by university staff.

1 INTRODUCTION

This paper provides preliminary analyses as a step toward assessing the value—to industry and society—of student research conducted via a bachelor's level digital construction course offered in Ireland since 2020. The course at Technological University Dublin (TU Dublin) provides employed, mature students with a one-year intensive study period (60 ECTS over 12 months) that runs alongside and interweaves with their daily work in Architecture, Engineering, and Construction (AEC) and ultimately yields the student an honours-level Bachelor of Science (BSc) degree (Level 8 on the Irish credentialing framework).

This BSc in Building Information Modelling (Digital Construction), aims to upskill individuals and inject new knowledge and skills across the Irish construction sector, enabling more effective practice regarding Building Information Modelling (BIM) and BIM Management (BIMM). BIM and BIMM are tools for creating and managing digital graphic representations and textural data regarding physical and functional characteristics a building or assembly. They are vital for AEC practitioners to learn, as they promote efficiency, reduce errors and inconsistencies, and drive innovation in design, construction, operations and maintenance phases of a project, thus contributing to a more sustainable and productive construction industry.

Obtaining a Level 8 degree in Ireland requires the student to produce a research dissertation, and this BSc course helps students use research skills and research thinking to answer pressing questions they encounter in the AEC context. Whereas our previous paper [1] summarized existing research on BIM education as context to situate this study in the literature, this paper provides a preliminary analytical mapping of the topics explored via formal research methods by our BSc level students over a three-year period.

The overall study of which this is part will help us assess quality and usefulness of research emanating from the BSc BIM course, identify pertinent themes across the set, and identify gaps or shortfalls in our coverage. This can help focus work more productively in the future, as we compare students' work with the prior studies of what has been researched by academics in Ireland [2, 3]. The work will support a larger effort to assess the degree to which BIM research produced at all levels in this institution (by BSc, Master's, and PhD students as well as academic staff) is helping meet industry and societal needs, enhance the use of BIM in Ireland, and facilitate change across Ireland’s AEC sector.

1.1 Prior work supporting this study

As noted above, this proposal builds upon preliminary work, published via the American Society for Engineering Education, on “Infusing Research Know-How into the Construction Sector: Pedagogies to Support Digital Construction in Ireland” [1] which explained existing strategies for the implementation of BIM at national levels, and pedagogies that can be used to support this shift toward digital construction. The paper started by discussing BIM adoption globally, the increasing use of BIM in Ireland, and the need for BIM education in Ireland. It then explained why research is needed to move the adoption of BIM forward and discussed how student research can support implementation of BIM in industry. It next described TU Dublin's scaffolded approach for supporting student researchers, and proposed a general plan to systematically map all BIM research produced at this institution.

1.2 Background on the university’s BIM courses

TU Dublin, one of the leading BIM education providers in Ireland, offers BIM courses that teach students how, among other things, to conduct publishable research studies to enhance the AEC sector in Ireland. The university has a Master of Science (MSc) degree program in applied Building Information Modelling and Management (aBIMM) in addition to the honors BSc in BIM/Digital Construction. The BSc and MSc degree courses, housed within the School of Surveying and Construction Innovation, use a scaffolded approach to support students in learning research skills.

Both courses require students to draw from and generate formal research. BSc research at TU Dublin provides a synthesis of existing publications on a topic of relevance in Ireland, resulting in a research paper to a “starter” conference paper standard. In the three years under review, the students had an eight-week course on basic research skills where they developed a plan for conducting their research (generating a research question and aligning it with three objectives, supported with specific methodologies) followed by one semester to conduct the study and write the dissertation. Given this short period of time, students were advised against conducting interviews or surveys but this was assessed on an individual basis. Nevertheless, some of the work is seen as valuable to the wider industry and some studies have been brought forward for presentation and publication at conference [4-6]. Beyond the BSc, BIM research produced by TU Dublin students and teachers includes conference papers, industry reports, and MSc and PhD thesis studies.

1.3 Rationale

TU Dublin’s BIM courses help address Ireland's recognized deficit in number of BIM-knowledgeable construction professionals. The courses provide working practitioners with experience using BIM in the context of discipline-specific modelling and multidisciplinary coordination. BSc research projects encourage students to implement a proposed solution to an industry-relevant context or within their organization. For the BSc, taught modules titled “Work Based Learning” and “Research Skills” help students identify and define industry-related problems relevant to their organizations that can be explored using formal research methods. Explicit goals are that the research output be relevant to the student’s employment setting, foster their career development, support their life-long learning and self-directed enquiry, and bring new ways of distilling answers into practice, thereby infusing industry with research know-how plus the BIM skills related to modelling, collaboration, communication, project management, and reflective practice. By equipping BIM students with research skills such as problem framing, literature review, and synthesis, the courses aim to develop future leaders for the field of BIM.

Engaging in BIM-related research projects BIM can help students develop their understandings of BIM technologies, standards, and processes as well as potential advantages of the technologies, how to collaborate effectively across sub-disciplines of AEC, and how to identify and address the challenges faced by industry stakeholders in adopting BIM. Students who are working in the AEC industry while they study can immediately share their new knowledge with colleagues as they apply it in practice.

With the BIM BSc course, launched in February 2020, now firmly in place and producing graduates, now is an optimal time to study and assess the quality and usefulness of our BSc research outputs. Our initial exploration will lay groundwork for subsequent, more extensive study of all BIM research generated at TU Dublin.

2 METHODOLOGY

This paper represents a second step in a larger study to systematically map and rigorously analyze all BIM-related research documents produced at TU Dublin, the first step being a review of pertinent literature [1]. The overall study uses practices for systematic mapping identified by Booth and Grant [7] and, within engineering education research, by Saunders-Smits and Cruz [8].

The methodologies employed to date have included narrative literature review [1], collection of all BSc dissertations submitted for graduation, import of this BSc dataset into NVivo, and preliminary analysis of the BSc titles and keywords. After importing the files, we ran NVivo a query to determine word frequency across the keywords and titles, including stemmed words. Then we tabulated the results of all terms occurring five or more times. We critically analyzed the results, assessing each term identified by NVivo and looking to see where there were overlaps based on the wider content where the term appeared. This allowed us to group terms, and begin to see themes and levels of concentration in coverage of various topics. For this paper we assessed the titles and keywords of 58 dissertations (we note that one dissertation was not formatted properly for inclusion in this analysis as it did not provide a title, keywords, nor abstract).

3 RESULTS

NVivo-indicated the most frequently used works were variants of BIM, a finding that is unsurprising. Fifty-five of the students used Building Information or BIM in their title or keywords. The other terms used with highest frequency were: construction (33 counts, used in the title and/or keywords of 17 students), implementing (17 used by 13), management (17 by 8), Ireland (16 by 14), lean (16 by 7), HBIM (14 by 7), and design (13 by 10). Figure 1 provides a cloud of word frequencies.

Fig. 1. Word cloud of most frequent words, considering titles and keywords only

Drilling down and assessing how each of the terms was used in context allowed us to identify themes, or areas of concentration in the work, as shown in Table 1, which highlights meaningful concentrations of topics. We see that 20 of the students had a major focus on national-level issues—frequently applying research on other countries to the Irish context. Many dissertations focused on implementing or adopting new processes or workflows in construction, and using new tools and software, particularly in architecture and design. Students showed concern for improving industry, especially practices in small and medium sized enterprises (SMEs), implementing lean and efficient practices, and using BIM in facilities management, heritage conservation, modular prefabrication, energy retrofits, and data centers (as Ireland has a high concentration and growing number of such centers). Other commonly investigated topics involved the public, digital engineering, integration, benefits and barriers, automation, collaboration, technologies, structural design, and cost.

Table 1 shows the terms in descending order based on the total number of students using the term in the title or abstract.

Table 1. Most frequent BSc dissertation topics

term	# students	occurrences
BIM or Building Information	55	228
Ireland or Irish	20	23
Construction	17	33
Implement* or adopt*	17	26
Process* or workflow*	17	20
(BIM) Tools, software, or Revit	15	23
Architectur* or design	11	20
Sector or industry	10	12
SMEs or enterpri*	9	6
Lean or efficient	8	18
Facilities [or] management	8	15
HBIM, heritage, historic, or conservation	7	35
Prefabrication or modular	5	13
Energy or retrofit*	5	13
Visual programming	4	15
Data cent*	6	13
Public	6	9
Digital	6	8
Engineering	5	6
Integrate*	5	5
Benefits	4	7
Barriers	4	7
Automate	4	5
Collabor*	4	5
Technolog*	4	5
Structural	3	9
Cost	2	5

* connotates allowance for various endings.

Boldface *indicates items grouped together based on qualitative analysis of the context in which terms were used.*

4 CONCLUSIONS

We believe that research and reflective practice are essential for the evolution of the digital construction field and that research generated by students and academics at our university is enhancing the knowledge base in Ireland. We further believe that learning to conduct research helps make students more effective practitioners they grow in skill and confidence and start to visualize themselves as leaders. They contribute in new ways to their companies and to improving the practice of construction in Ireland. The analyses presented in this paper constitute one step toward helping us verify the value and research of the BSc course, and confirm the success of teaching BIM BSc students how to conduct research.

Work conducted to date provides a straightforward mapping of the terrain. Later steps will include analysis of the abstracts produced, objectives stated, and methodologies utilized by students, to include MSc in addition to BSc thesis work. Most prior BSc studies have synthesized existing literature to generate new knowledge—for the student and for society at large—by integrating across sources, and also comparing and contrasting existing cases. Many of the students have generated new models, workflows, frameworks, or processes as a result of comparative study. Others have chosen to apply synthesized literature to a new case; and a number of students have employed action research methodologies. Overall, literature review, case study, and action research have been the primary methodologies used.

Of the 59 BSc dissertation studies completed since the 2020 course launch, three have been further developed, presented at conferences, and published in proceedings [4-6]. One generated a new framework to achieve energy-efficient design [4], one optimized a workflow to facilitate structural design [5], and one made recommendations to enhance Ireland’s estates management within the health care sector.

The reported analysis of BSc work will inform our subsequent, larger study—a systematic review of all BIM research originating from TU Dublin which will assess coverage of topics, identify gaps, and evaluate the quality and usefulness of the accumulated work. This particular mapping of BSc documents has enhanced the research team’s skill in applying systematic review methodologies to help us achieve higher aims in the future. We will subsequently critique the quality and depth of research produced across this institution, summarize key findings, and generate recommendations for BIM research and BIM industry in Ireland.

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HOW TO CHARACTERISE PERFORMANCE IN ENGINEERING FRESHMEN'S MODELLLING TASKS?

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ABSTRACT

This paper presents a study aiming at characterising engineering freshmen's performance in modelling tasks, as well as the strategies they adopt to execute them, before and after taking a 3-D modelling course. 97 freshmen in a French engineering school were asked to produce 3-D models of a part, using three views and the product development platform Onshape. The accuracy of their models was assessed using geometrical, dimensional and functional criteria. The students' performance was also investigated with regards to their modelling strategies. We characterised more specifically the strategies they adopted to constrain the overall length of the part, and pierce the central key groove. We complemented this experiment with spatial visualisation and spatial orientation tests, to explore the potential relation between modelling performance and spatial ability. We identified two strategies for piercing the key groove and three for defining the total length of the part. We observed that the latter was linked to the students' spatial ability, unlike the key groove piercing strategy. We observed a significant increase in the number of students who adopted an efficient strategy to define the length of the part after the 3-D modelling course. This increase seems to indicate that more students were able to take into account visual information regarding size. We nevertheless observed a lack of progression in the ability to dimension this element accurately. This confirms the unchanging need for teaching students, as well as pupils, how to read and interpret 2-D information.

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1 INTRODUCTION

Product design aims at manufacturing great volumes of goods, in short lead time, at low costs (Geronimi et al. 2005, 118). Nowadays, designers use Computer Aided Design (CAD) tools to produce dynamic trustworthy complex representations of objects, making “manufacturing more time and cost-efficient” (Brown 2009, 54). This professional practice has greatly impacted the curricula of the schools where mechanical design is taught: descriptive geometry and engineering graphics have been replaced by 3-D modelling courses (Ault and John 2010, 13). In 2016, the French government decided to investigate the impact of the increasing role played by digital tools on learning, by sponsoring research programmes addressing this issue[2]. EXAPP_3D, an e-FRAN project, aimed at better understanding how multi-purpose 3-D modelling software was used by learners at different levels of schooling. This project provided the opportunity to investigate spatial ability and its possible inferences as a necessary ability in French engineering education. More specifically, this work aims at studying how engineering freshmen’s modelling performance and strategies evolved following an introductory 3-D modelling course. A secondary objective is to explore whether the initial performance is linked to spatial scores.

2 RESEARCH CONTEXT

2.1 Teaching 3-D modelling

3-D modelling courses have a twofold aim: they must teach students how to use 3-D modellers, as well as how to best use them (Rynne and Gaughran 2007, 59): students need to learn not only how modellers work and the functions they offer, but also efficient strategies that enable them to make the most of parametric modelling (Chester 2007, 23; Rynne and Gaughran 2007, 57). Commands are specific to a modeller, whereas strategies can be used in any modeller (Hamade, Artail, and Jaber 2005, 306). Unlike learning software commands, learning efficient strategies is difficult as there are several ways of designing an object (Bertoline et al. 2009, 416). The difficulty lies in developing strategies which are time-efficient and limit the number of mistakes (Bhavnani, Reif, and John 2001, 230).

Creating an object in a 3-D modeller follows a procedure, which can be observed in professional practice (Hartman 2005, 11) and in modelling courses (Bertoline, Hartman, and Adamo-Villani 2009, 640):

- Choice of a sketch plane in a 3-D space,
- Sketching of a 2-D profile on the chosen plane,
- Dimensioning and constraint of the sketched profile,
- Application of a feature to the 2-D profile, or part of it.

The effective use of CAD tools therefore requires strategic knowledge (Bhavnani, Reif, and John 2001, 229), mathematical and computing knowledge (Ye et al. 2004, 1454), the ability to break down a solid into elementary geometrical parts (Rynne and Gaughran 2007, 55), and that to understand numerical representations relating to size, shape and orientation (Bertoline et al. 2009, 6).

[2] Espace de formation, de recherche et d’animation numérique (e-FRAN) projects are supported by the Ministère de l’enseignement supérieur, de la recherche et de l’innovation.

Modelling performance can be measured by assessing the accuracy of the models, and the strategies used (Chester 2007, 30; Steinhauer 2012, 47): these can be observed for example in the feature tree, which shows the final order of the sketches and the features used to produce the model.

2.2 Spatial ability

The ability to understand, recognise, and manipulate 2-D and 3-D representations has been named spatial ability (Linn and Petersen 1985, 1482; Lohman 1993, 3). It is often subdivided into several factors; the most quoted factors are spatial visualisation and spatial orientation (McGee 1979, 889; Hegarty and Waller 2004, 175). Tartre (1984) bases her classification on this distinction, which separates skills requiring the mental manipulation of shapes, from those involving the perspective of the viewer (6). She subdivides the two factors depending on the portion of the shape is involved: regarding spatial visualisation, she refers to Kersh and Cook's distinction (1979, in Tartre 1984, 8) between mental rotation, where the whole shape is manipulated, and mental transformation, which involves part of an object. Similarly, spatial orientation can be divided into the reorganised whole category, which concerns the "organization and comprehension of an entire pictorial representation or a perceptual change from one representation to another" (Tartre 1984, 16). On the other hand, the part of field category describes "the relationship of part of a representation to the whole field, either presented visually or imagined" (20). Tartre's classification is illustrated in Figure 1.

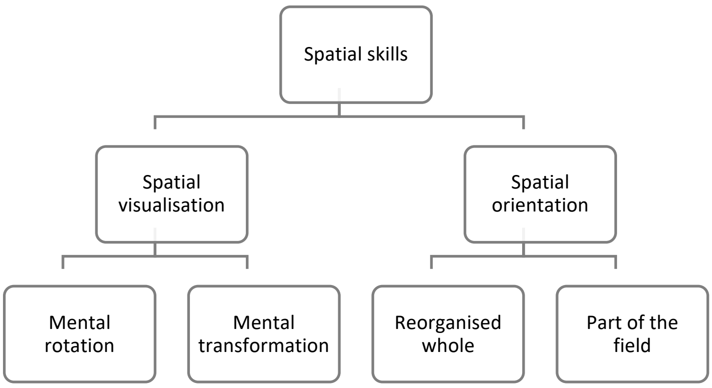


Fig. 1. Adapted from Tartre's spatial skills classification scheme (1984, 27)

These skills are often assessed through psychometric pen-and-paper tests (Eliot and Macfarlane Smith 1983). We will present here five tests, which aim at measuring one of the components of Tartre's classification.

The Mental Rotation Test (MRT) (Vandenberg and Kuse 1978) and the Revised Purdue Spatial Visualization Tests: Visualization of Rotations (R PSVT:R) (Yoon 2011) aim at measuring mental rotation. The Special Aptitude test in Spatial Relations, better known as the Mental Cutting Test (MCT) (College Entrance Examination Board 1939), seeks to evaluate mental transformation. These three tests involve mental manipulation of 3-D objects.

The Purdue Spatial Visualization Test: Visualization of Views (PSVT:V) (Guay 1976) aims at measuring the change of perspective. The Closure Flexibility Test (Concealed figures) Form A (CFT) (Thurstone and Jeffrey 1956) solicits the ability to isolate a shape embedded in a larger figure. These two tests come under spatial orientation, as they ask respondents to recognise and understand shapes.

Performance at spatial tests has been linked to academic success in Science, Technology, Engineering and Mathematics (STEM) (Wai, Lubinski, and Benbow 2009, 827): these disciplines require students to visualise, manipulate and understand 2-D and 3-D shapes. More specifically, several studies have demonstrated a relationship between spatial performance and 3-D modelling (Steinhauer 2012, 47; Branoff and Dobelis 2012, 40).

2.3 Research question

3-D modelling courses hold a two-fold objective: teaching students how to use 3-D modellers, and how to use them efficiently. The objective of this study is to characterise engineering freshmen's performance in modelling tasks, as well as the strategies they adopt, before and after taking a 3-D modelling course. As spatial ability has been described as a predictor of success in 3-D modelling, a secondary goal is to explore the potential relation between students' spatial ability and their modelling performance, before they undertake a modelling course.

3 METHODOLOGY

3.1 Participants

The experiments were scheduled at the beginning of the year, and at the end of the first term of the first-year course. The participation of the students varied according to the assessment. In this paper, we will describe the performance and strategies of the students who took part in all the experiments.

Our sample consisted of 97 freshmen in a French engineering school, aged between 18 and 21, mean 19.9. There were N_F = 20 [20.6%] women and N_H = 77 [79,4%] men. French engineering students join a school after taking competitive entry exams following two-year intensive preparatory courses, the first two years of a university degree, or obtaining a two-year vocational qualification. 54 [55.7%] students had been exposed to technological content prior to joining the school, whereas 43 [44.3%] came from courses deprived of technological content. 86 [88.7%] students had some experience with 3-D modellers, when 11 [11.3%] had none.

3.2 Instruments and procedure

3.2.1 Modelling experiment

In September 2019, the students were asked to produce 3-D models of a part, using three views, one of which included dimensions, as illustrated in Figure 2, and the online product development platform Onshape (Hirschtick et al. 2014). We decided not to use technical drawings, as some of the students lacked a technical background and might find the drawings difficult to interpret. The students were first asked to follow a tutorial to learn how to use the software. They completed the same modelling task in December 2019, that is to say at the end of the first term, during which they received a 10-hour 3-D modelling course using the CATIA software (Dassault Systèmes 2012).

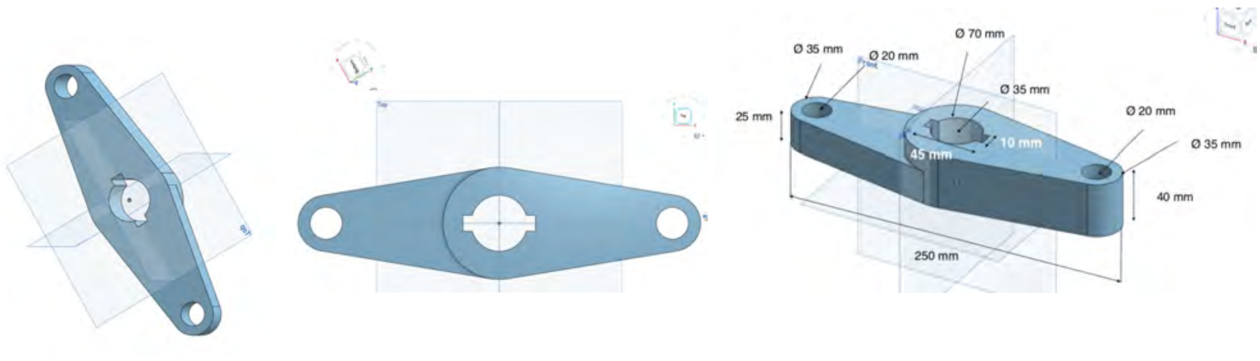


Fig. 2. Modelling assessment

Technical drawings were generated to assess the students' models, using geometrical, dimensional and functional criteria, the details of which are illustrated in Figure 3. We allocated a further point for the trimming of excessive elements. The total score was 35.

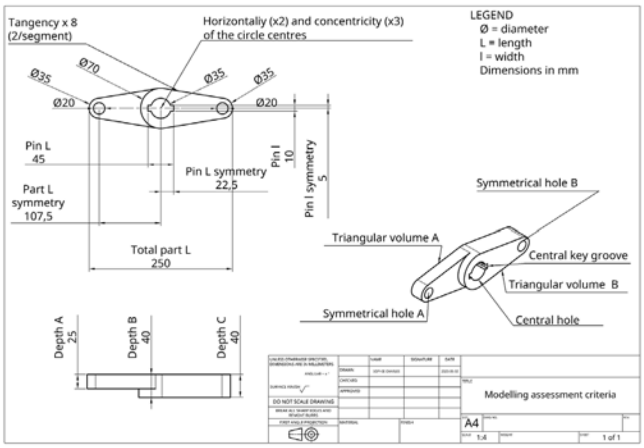
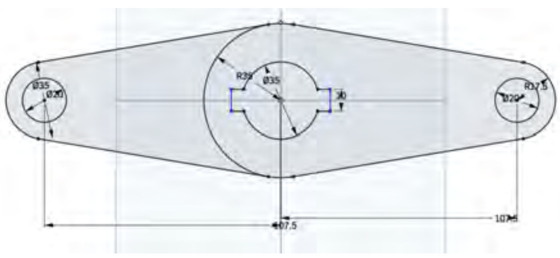


Fig. 3. Modelling assessment criteria

The students' performance was also investigated with regards to their modelling strategies. We observed 3 different procedures for constraining the total length of the part:

- Strategy 1: defining it as a combination of different elements, as illustrated in Figure 4;
- Strategy 2: defining it as a unique dimension, as illustrated in Figure 5;
- Strategy 3: not allocating it a dimension.



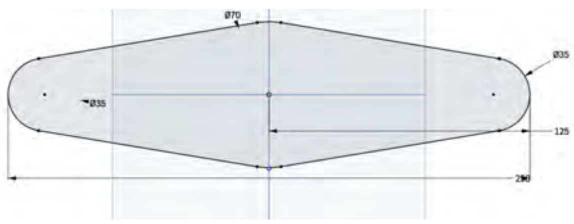


Fig. 4. Length defined as a combination *Fig. 5. Length defined as one dimension*

We finally consulted the feature tree to observe the sequence of sketches and extrusions, to determine the strategy the students adopted to pierce the central key groove. Two behaviours were identified: some students pierced it in one or several extrusions without filling it, while others did it in several extrusions, some of which led to the obstruction of the key groove. The latter group pierced the central key groove, filled it with a further extrusion and pierced it a second time. This strategy is illustrated in Figures 6 and 7.

Fig. 6. Piercing of the central key groove

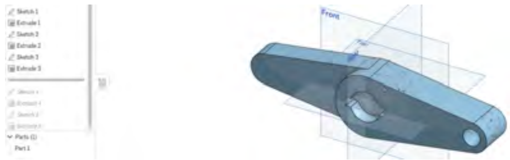


Fig. 7. Obstruction of the central key groove

Spatial tests

In September and December 2019, 97 freshmen took a battery of five spatial tests under the following testing times:

- PSVT:V: 20 minutes, according to the description in Eliot and Macfarlane Smith (1983).
- MRT: 3 minutes to complete each part. They were separated by a 3-minute break. Such timing was deemed appropriate for our sample by one of the authors (Allan R Kuse, e-mail to author, June 25, 2018).
- MCT: 20 minutes, as prescribed in the instructions.
- R PSVT:R: one hour for timetabling reasons. This aligned with the author’s indication that most students complete the test in 30 minutes (So Yoon Yoon, e-mail to author, May 16, 2018).
- CFT: 10 minutes, according to the instructions (Thurstone and Jeffrey 1965).

The instructions of the tests were translated in French, except for the MRT whose French version was available (Albaret and Aubert 1996), so that English ability would not affect student performance. We used the pen-and-paper versions of the tests. The students answered directly on separate answer sheets for the PSVT:V, the MCT and the R PSVT:R, but answered on the question papers and reported their answers on the answer sheets after the test, for the MRT and the CFT. The students were instructed to not guess the answers. The scores were calculated according to the instructions.

3.2.2 Data analysis

We first checked the normality of the distribution of the scores for the spatial tests and the modelling assessments by using the Shapiro-Wilk test (Shapiro and Wilk 1965) in SPSS (IBM Corp. 2021). Only the CFT scores followed a normal distribution. We consequently opted for parametric tests for the CFT and non-parametric tests for the other assessments:

- Spearman correlations were calculated to explore the link between modelling performance and spatial scores. They were completed with the study of scatter charts to check the validity of the correlations (Kinnear and Gray 2015, 290).
- The sign test was used to compare the evolution of the modelling scores and strategies, as it is deemed more robust than the Wilcoxon signed-rank test (Kinnear and Gray 2015, 174).
- The Kruskall-Wallis test (Kruskal and Wallis 1952) was used to compare the performance of groups of students according to their modelling strategies, for

the PSVT:V, the R PSVT:R, the MRT, and the MCT. One-way ANOVAs were performed to compare CFT scores between groups of students according to their modelling strategies. When a significant result was observed, box plots were generated to interpret the result.

4 RESULTS

We will first present the results for the initial performance, followed by those regarding the performance measured at the end of the first term, and finally the results concerning the evolution, or lack of, in performance and strategies between the two sets of experiments.

4.1 Initial modelling performance and strategies

4.1.1 Accuracy of the model

As mentioned in paragraph 2.2.2, most students obtained high and very high modelling scores when they first joined the school. The descriptive statistics are available in Table 1. This can be partly explained by the fact that most students had some prior experience with 3-D modellers.

Table 1. Descriptive statistics for the modelling assessments

Testing date	Mean	Median	Standard deviation	Minimum	Maximum
September	31.16	33.00	4.64	12	35
December	32.85	34	3.12	13	35

4.1.2 Dimensioning of the length of the part strategy

A majority of the students (*n* = 70; 72.2%) split the total length into several dimensions, some of them (*n* = 15; 15.5%) did it by dimensioning the length between the two ends of the part, while other students (*n* = 12; 12.4%) did not dimension enough elements to constitute the total length of the part. Furthermore, 51 [52.6%] students defined the total length of the part successfully, when 46 [47.4%] students did not. These results seem to indicate that a minority of the students did not fully exploit the information in the view with the dimensions. They also show that about half the students failed to determine the length successfully, whether they did not enter enough dimensions to define it, made a mistake in calculating it, or entered the wrong overall dimension. This suggests a lack of understanding and/or interpretation of the information given in the view with the dimensions.

4.1.3 Piercing of the central key groove strategy

A majority of the students (*n* = 88; 90.7%) pierced the central key groove without refilling it, whereas a small number did (*n* = 9; 9.3%). This indicates that the latter group failed at analysing the volumes which compose the part, and consequently at efficiently planning their modelling activity.

4.1.4 Relationship between the students' spatial ability and their modelling performance

Except for the CFT scores, our sample's spatial performance was fairly high. The details can be found in Table 2. This result can be explained by the fact that French engineering school students are recruited through highly selective processes and that they join the school after two-year courses with mathematics, physics, chemistry and/or technological courses (Charles et al. 2019, 240). The difference in the CFT scores may be due to skills developed outside of formal education.

Table 2. Descriptive statistics for the spatial tests

Spatial test	Highest possible score	Mean	Median	Standard deviation	Minimum	Maximum
PSVT:V	30	25.48	27.00	4.98	5	30
R PSVT:R	30	25.75	26.00	3.71	11	30
MRT	20	13.34	14.00	4.03	0	20
MCT	25	16.93	18.00	4.83	5	25
CFT	196	99.86	100.00	26.53	22	160

In Table 3, we observe significant positive relationships between modelling and spatial scores, except for the MRT.

Table 3. Spearman correlation for spatial scores in function of modelling scores

Dependant variable	Independent variable	r_S	*p*
Modelling scores	PSVT:V	0.34	0.001**
	R PSVT:R	0.31	0.002**
	MRT	0.16	NS
	MCT	0.31	0.002**
	CFT	0.24	0.017*

Note. r_S = Spearman's coefficient; *p* = p value.

On the scatter charts in Figures 8-11 , we observe that modelling scores starting from 25, that is about 95% of our sample, are more or less gathered around the correlation axis. This explains that the correlation coefficients are weak despite the significant result.

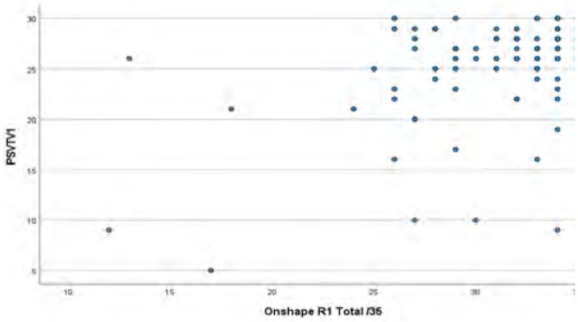


Fig. 8. Scatter chart of the modelling and the PSVT:V scores

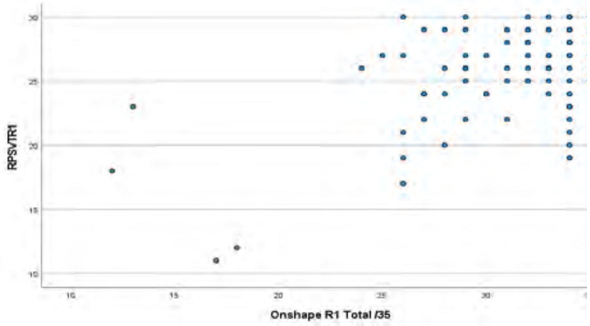


Fig. 9. Scatter chart of the modelling and the R PSVT:R scores

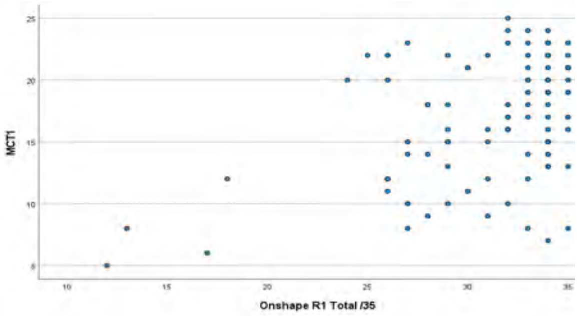


Fig. 10. Scatter chart of the modelling and the MCT scores

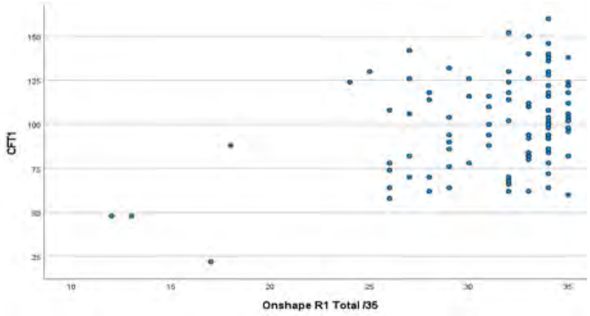


Fig. 11. Scatter chart of the modelling and the CFT scores

4.1.5 Relationship between the students' spatial ability and modelling strategies

The Kruskall-Wallis test reports a significant relationship between the performance at the PSV:T ($p < 0.01$), the R PSVT:R ($p < 0.05$), the MCT ($p < 0.01$), and the choice of strategy for defining the overall length of the part. On the other hand, a nonsignificant result is obtained for the MRT. The results are described in Table 4.

Table 4. Relationship between the length-definition strategy and the PSV:T, the RPSVT:R, the MRT and the MCT

Spatial test	$\chi^2(2)$	*p*
PSVT:V	10.19	0.006**
R PSVT:R	7.32	0.026*
MRT	3.43	NS
MCT	12.487	0.002**

Note. χ^2 = test statistic; () = degree of freedom; *p* = p value.

The one-way ANOVA comparing the CFT scores and the length-definition strategy indicates a significant result: $F(2,94) = 6.24$; $p = 0.003$. The box plots in Figures 12-15 show that the students who used Strategy 1 and 2, i.e. by constraining the length in one or several dimensions, obtained the best scores at the PSV:T, the R PSVT:R, the MCT and the CFT.

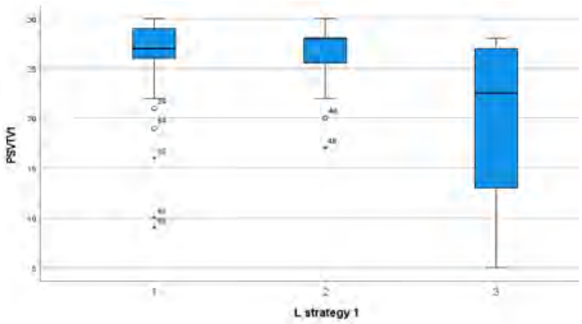


Fig. 12. Box plot of the PSVT:V scores according to the L strategy

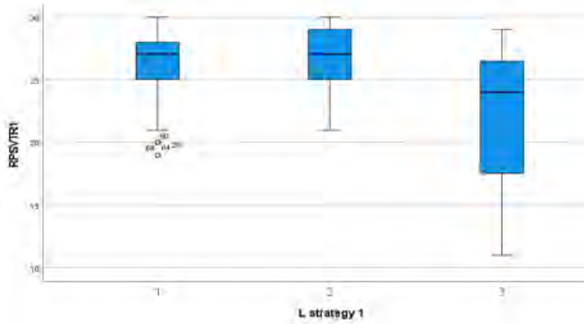


Fig. 13. Box plot of the R PSVT:R scores according to the L strategy

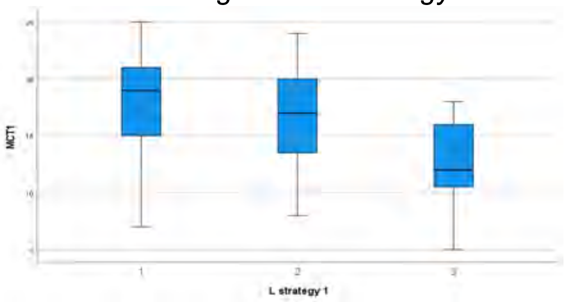


Fig. 14. Box plot of the MCT scores according to the L strategy

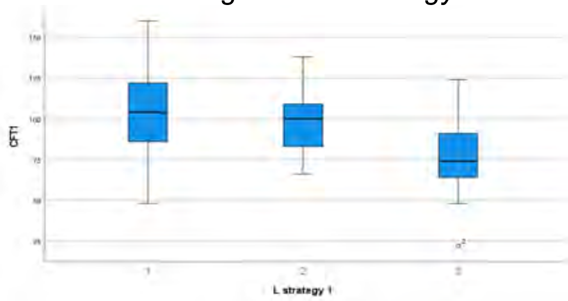


Fig. 15. Box plot of the CFT scores according to the L strategy

The Kruskall-Wallis test does not produce a significant result regarding the relationship between the performance at the PSV:T, the R PSVT:R, the MRT and the MCT and the key groove piercing strategy. We obtain a similar result with the one-way ANOVA for the CFT. These results suggest that spatial ability is not involved in the capacity to select the correct surface when extruding.

4.2 Evolution after the CAD course

4.2.1 Accuracy of the model

The sign test indicates a very significant result ($p < 0.01$) in the evolution of the modelling scores. The boxplots in Figure 16 show that the students' performance increased, and that the distribution of scores narrowed at the end of the term. Nevertheless, a few students progressed but underperformed at both assessments.

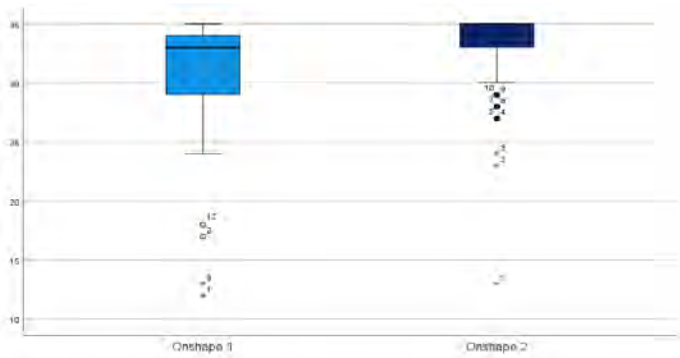


Fig. 16. Distribution of modelling scores before and after the modelling course

We calculated the amount of progression which can be attributed to the practice effect, that is "any change or improvement that results from practice or repetition of task items or activities" (American Psychological Association n.d.), as we used the same modelling task for both experiments. The increase in performance described in Table 5 (0,5σ) is greater than the practice effect, which accounts for 0.2σ improvement for identical tests, taken at an interval greater than three months (Hopkins 1998, 140). This suggests that part of the progression is due to the teachings the students received.

Table 5. Assessment of the practice effect

Mean gain	Standard deviation	Mean gain / Standard deviation
1.7	3.4	0.5

Unlike this overall progression, the number of students who defined the total length of the part did not evolve significantly: 53 [54.6%] students defined the total length of the part successfully, when 44 [45.4%] students did not. This suggests the CAD course helped the students model more accurately in general, but did not have an impact on the students' ability to either define, or calculate the total length of the part accurately.

4.2.2 Dimensioning of the length of the part strategy

The sign test to compare the number of students according to their length-defining strategy indicates a significant result ($p = 0.015$): the bar charts illustrated in Figures 17 and 18 show that more students used the combination strategy (Bar 1 in both illustrations) at the end of the term, that is to say they dimensioned several components of the overall length after calculating them; whereas fewer students failed to dimension the length of the part (Bar 3 in both illustrations).

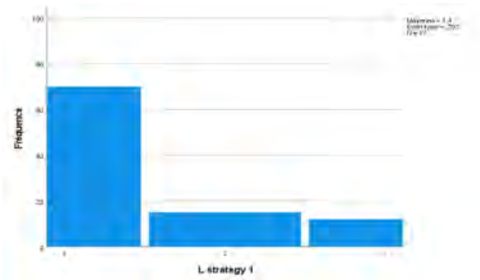


Fig. 17. Distribution of the length-defining strategies before the modelling course

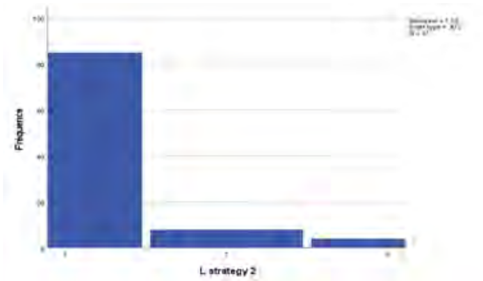


Fig. 18 Distribution of the length strategies-defining after the modelling course

4.2.3 Piercing of the central key groove strategy

The sign test to compare the number of students according to their key groove piercing strategy indicates a nonsignificant result, although fewer students ($n = 3$; 3.1%) obstructed the central key groove at one point of their modelling activity in December. This result may be due to the very low number of students ($n = 9$; 9.3%) who had this problem in the first experiment.

4.3 Limitations

The results presented here are limited by the methodology we adopted:

- As participation in the experiments was voluntary, it is possible that the students in our sample are characterised by a certain motivational profile and/or a certain aptitude for 3-D modelling. This was controlled with a Mann-Whitney *U* test to compare the performance of the students on the CAD course assessment according to their participation in the experiments. It showed a nonsignificant difference in performance between the students who took part (n = 123; 91%), and those who did not (n = 12; 9%).

- The order of the tests in our spatial battery may have affected the performance of the tests placed after the first test: the students may have acquired knowledge in the first test(s), which may have benefited their performance in the later tests (Kinnear and Gray 2015, 241). A random order of the tests would help to counterbalance this effect.

5 SUMMARY AND ACKNOWLEDGMENTS

This paper aimed at characterising engineering freshmen's performance in modelling tasks, as well as the strategies they adopt, before and after taking a 3-D modelling course. Our sample's initial modelling performance, which was fairly high, is significantly correlated to their spatial ability at four of the tests in our battery, although the coefficient is quite low. Furthermore, we observe a significant result for the link between spatial performance at four of the tests in our battery and the strategy for defining the total length of the part, that is not reflected in the relationship with the key groove piercing strategy. These results seem to indicate that spatial skills are more involved in the identification and comprehension of basic geometric information such as numerical representations relating to size, shape and orientation (Bertoline et al. 2009, 6), than the breaking down of a solid into elementary geometrical parts (Rynne and Gaughran 2007, 55). Our results also demonstrate the relevance of using spatial orientation tests to explore the relationship between spatial ability and 3-D modelling, when most studies tend to use spatial visualisation tests (Steinhauer 2012; Branoff and Dobelis 2012). In this study, both our spatial orientation tests were linked to modelling performance and strategy, unlike the MRT, a visualisation spatial test. The CFT especially has been relevant in identifying links between spatial ability and 3-D modelling performance and strategies in some of our other experiments (Charles 2023).

Our study shows a positive impact of the CAD course on the students' overall modelling performance and strategy, as more students adopt a length-defining strategy at the end of the term. These findings tend to confirm the transferability of 3-D modelling skills form one modeller to another (Hamade, Artail, and Jaber 2005, 306): 3-D modelling strategies acquired in the CAD course using CATIA were observed in the experiment using Onshape. However, we can notice that this change of strategy is not more efficient in producing the accurate dimension. This suggests that more work needs to be done on basic 2-D geometry relating to size and understanding of 2-D representations of 3-D objects at the engineering education level. This also confirms previous studies which have argued for more geometry to be taught in earlier education (Duroisin 2015; Maier 1996), so that students come fully equipped when they enter engineering education.

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Contributing Factors to Academic Well-being: Mechanical Engineering Students' Perspectives in A PBL Context

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Conference Key Areas: Recruitment and Retention of Engineering Students; Fostering Engineering Education Research

Keywords *Academic well-being; Q methodology; PBL; Engineering student*

ABSTRACT

In a post-pandemic learning era, student academic well-being emerges to the attention of educational researchers. Referring to students' thoughts and behaviors that contribute to doing well in an educational context and their academic life satisfaction, student academic well-being has a significant influence on their recruitment and retention, learning experience, academic achievement, and competence development.

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However, while academic well-being has been regarded as an important indicator of student persistence in their current study and learning outcomes, limited studies have explored engineering students' academic well-being and other supportive factors in engineering education. While several studies have examined how well-being is constituted and how it can be measured from medical, mental health, and eudaimonic philosophical perspectives, understanding engineering student academic well-being from social-cognitive and sociocultural aspects is also important. This is because well-being is not only influenced by personal feelings and perceptions, but also dynamically framed by interpersonal relations, as well as contextual and institutional conditions. To increase retention and help engineering students to become agentic professionals, it is desirable to help them to become proactive and purposeful learners in their studies.

Thus, aimed at filling in this literature gap, this study will adopt the Q methodology to explore how engineering students perceive the sources contributing to their academic well-being in a Danish university. Suggestions will be proposed to optimize future curriculum design to support student academic well-being.

1 INTRODUCTION

In a post-pandemic learning era, students' academic well-being in higher education has gained attention due to its significant influence on students' persistence in their majors, learning experience, academic performance, and competence development (Huamán and Berona 2021; Korhonen et al. 2014). Academic well-being refers to students' views and behaviors contributing to doing well in an educational context and their academic life satisfaction (Donohue and Bornman 2021; Shek and Chai 2020). Understanding students' academic well-being and related impact factors enables educators to help students have better learning experiences and become agentic professionals by optimizing the current learning environment. In engineering education, a rich body of literature has conceptualized and measured students' well-being from diverse perspectives ranging from philosophy and psychology to medicine and mental health (Castro-Sitiriche et al. 2012; Danowitz and Beddoes 2020; Telang et al. 2021). Such efforts provide insights into complex components of students' academic well-being, nevertheless, it remains unclear how the learning environments foster and support students' academic well-being by providing various sources for their learning. Thus, this study explored how engineering students perceive the supportive sources of their academic well-being, particularly, in PBL contexts. Methodologically, the study contributes to the current literature by adopting Q methodology to provide insights into students' subjectivity related to the attainment and improvement of their academic well-being. The research question in this study is:
What are the contributing factors to engineering students' academic well-being from engineering students' perspectives?

2 RESEARCH CONTEXT

This research project is carried out at a leading Danish University that adopts a systemic PBL curriculum design for both undergraduate and graduate engineering programmes. In each semester, students are expected to gain 15 European Credit Transfer System (ECTS) credits from courses and projects separately. In this systemic PBL practice, students become the center of learning by identifying, analyzing, and solving real-life problems in teamwork, while educators take the role of supervisors to facilitate students' learning process. Within this context, students' engagement in the learning environment, with multiple human and non-human resources has a significant influence on their learning outcomes, competence development, learning experience, as well as academic well-being. While the academic benefits of a systemic PBL curriculum design on students' learning experience and competence development have been reported (Kolmos et al. 2021), more attention is needed to explore in which ways students' academic well-being could be supported in this specific learning context. Thus, as a part of a research project on academic well-being, this paper presented a pilot study using a 31-item Q-sort to explore students' perspectives of sources fostering their academic well-being. This study has received ethical approval from the university.

3 METHODOLOGY

Q methodology is primarily concerned with exploring subjectivity by providing a holistic understanding of participants' internal viewpoints (Ellingsena et al. 2010). It has been identified as a "quali-quantological" method because it enables researchers to gain qualitative findings through applying statistical analysis methods (Parker and Alford 2010). Prior studies identified five steps in conducting Q methodology (Ellingsena et al. 2010; Brown 1980), which are 1) identifying the concourse; 2) developing a Q set with representative statements; 3) specifying the respondents (P-set); 4) implementing Q sorting and post-sorting activities; and 5) conducting factor analysis and interpretation.

3.1 Concourse and Q Set Development

In this study, the Q concourse, which refers to a collection of all conceivable statements related to a specific topic (Brown 1980), was developed using a theoretical framework of sources fostering students' academic well-being. Based on a literature review on academic well-being in higher education and validated by the authors' prior study (Chen et al. 2023), this proposed framework contains two domains, including internal sources and external sources. Specifically, internal sources refer to students' personal values and attitudes, such as intrinsic motivation, autonomy, intention, and self-efficacy, that support their academic well-being throughout the study process (Lewis et al. 2009; Stanton et al. 2016; Schmidt and Hansson 2018). External sources focus on the supporting factors from the learning environment that foster students' academic well-being, including interactions with peers, interactions with professionals, support from family and friends, and available resources from the learning environment (Larcus et al. 2016; Trolian et al. 2022; Yukhymenko-Lescroart et al., 2015).

Table 1. Q set of sources for engineering students' academic well-being

Domains	Themes	Statements
Internal sources	Personal values	- Enjoying what I study - Feeling motivated in my study - Aspiring for a good career through my academic work - Choosing my study program following my interest - Taking responsibility for my own learning process - Developing professional competencies through my study - Working with people from diverse backgrounds - Feeling financially secured for my study - Having a balance between study and my personal life
	Agentic actions	- Monitoring my academic growth to reach my goals - Being able to solve academic problems - Having clear goals for my academic success - Managing my time well - Making decisions based on what I think is important - Challenging myself to reach my full (academic) potential - Being able to accomplish academic tasks well - Being able to manage stress related to academic work (e.g., stay calm during exams, work towards deadlines, etc.)
External sources	Interactions within learning environments	- Communicating with my peers efficiently - Expressing my opinions comfortably in group discussions - Developing teamwork strategies together with my peers - Reflecting with my peers on our progress toward common goals - Making contributions to the team - Experiencing mutual trust in my study context - Feeling comfortable in the physical study environment - Feeling my performance is fairly assessed in my study context
	External support	- Sharing my academic experience with my family - Communicating efficiently with my instructors/supervisors - Sharing my academic experience with my friends outside my study - Communicating with professional communities (e.g., industry, companies, associations) - Having access to needed resources (literature, databases, software, library services, etc.) in my study - Having access to student support/consulting services at the university

With the guide of this theoretical framework, a 37-item survey was designed and validated in the authors' prior empirical study (Chen et al. 2023). An initial concourse was further revised and condensed by the research team and later reviewed through two rounds of expert review and one round of student review and pilot, in which process six statements were deleted because of overlap or irrelevance. The final Q set for this study contained 31 statements, shown in Table 1.

3.2 Data Collection and Analysis

With a Q set extracted from the concourse, this study identified engineering students as the respondents (P-set) (McKeown and Thomas, 2013). Participants were recruited from a mechanical bachelor program with students in their fourth-semester study. Among 43 students, 13 students volunteered to participate in this Q study and provided effective responses, including one female, ten males, and two students who preferred not to specify their genders. This is an acceptable number to provide various perspectives in Q methodology.

With the Q set of various sources printed on individual cards, a paper-based version of the Q sorting activity was completed by the participants. They responded to the following condition of instruction: "Based on your experience, what aspects/factors contribute to your academic well-being", and then ranked the statements from "most relevant" (+4) to "least relevant" (-4).

After the Q sorting, participants were invited to answer several post-sorting questions, including their background information (e.g. gender, semester, nationality, and discipline), and the reasons for their choice of the two most/least ranked items.

Table 2. Results of the factor analysis

Part. No.	Factor Group	Factor 1	Factor 2	Factor 3
Factor One				
10	F1-1	0,6983	0,0292	0,1947
9	F1-2	0,6415	0,4285	0,1256
3	F1-3	0,6225	0,1433	0,4468
13	F1-4	0,6102	0,1421	–0,1102
4	F1-5	0,5813	0,3937	–0,3991
12	F1-6	0,5186	0,3347	0,2150
5	F1-7	0,5170	0,1065	0,3119
Factor Two				
6	F2-1	0,1502	0,9053	0,2550
11	F2-2	0,1321	0,8092	0,3110
Factor Three				
8	F3-1	0,0032	0,1111	0,7686
7	F3-2	0,4272	0,3594	0,5901
Unloaded Statements				
2	F1-8	0,3771	0,2363	–0,0363
1	F2-3	0,1981	0,4015	–0,0426

The last step in Q methodology is factor analysis and interpretation. Using centroid extraction followed by theoretical rotation (Brown 1980), factor analysis was conducted via a Q-analysis software named KADE to identify correlations between the sorting results from participants. A three-factor extraction solution was decided, based on statistical standards and meaningful interpretation of participants' viewpoints (Brown 1980). The results of the factor analysis, explaining 55% of the opinion variance, are reported in Table 2.

4 RESULTS

This section illustrates three different viewpoints emerging from the Q sorting and factor analysis. The numbers of statements are indicated in brackets, along with the assigned values in the specific factor array. For example, #1/+4 means that statement 1 has the value of 4 in the factor array of the specific viewpoint. "D" shown in the brackets indicates a significantly distinguishing statement from other factors (*p*-value < .05), while "D*" refers to a higher level of significance (*p*-value < .01).

4.1 Viewpoint 1 – Doing academically well while maintaining a healthy balance

Seven participants, including one female and six males, loaded significantly on Viewpoint 1, accounting for 23% of the variance. These students highlighted internal aspects contributing to academic well-being, which focused on developing their academic competence and maintaining a healthy study-life balance, as the most relevant source to support their academic well-being. As a majority group of participants, students in Viewpoint 1 emphasized their ability to accomplish academic tasks well (#2/+4, D*) and solve academic problems (#1/+2, D*). They also valued a healthy balance between study and life (#10/+4, D*), which distinguished them from other viewpoints. This perspective was further reflected in their post-survey questions, as one wrote, "*I need to have a good balance between school and my life because my free time is important to me, otherwise I would feel burnt out* (F1-1)".

In general, participants in this group ranked external aspects less relevant to fostering their academic well-being. In particular, they did not value peer support (#6/-1; #7/–1), interdisciplinary/intercultural teamwork (#22/–4), or mutual trust in their learning context (#15/–2, D), as supportive sources for their academic well-being. As explained by Viewpoint 1 participants in the post-sorting questions, these external sources were not considered a priority from a technical point of view, such as to become a good engineer in the future, while academic qualities were highly valued in the engineering field. Thus, they did not feel that the physical learning environment nor teamwork skills had an impact on their academic well-being. Further, a few other aspects were ranked less relevant to their academic well-being, such as making decisions based on what they thought was important (#17/–2, D*), feeling financially secured for their study (#19/–1, D*), and taking responsibility for their learning process (#29/–1).

4.2 Viewpoint 2 – Enjoying the study with intrinsic motivation

Viewpoint 2 comprised two participants (one male and one preferring not to say) and accounted for 19% of explained variance. In comparison to Viewpoint 1, participants in this group also highlighted the contribution of internal aspects to their academic well-being, but with different emphases. Viewpoint 2 participants highly valued their intrinsic motivation, emphasizing the enjoyment of study (#21/+4), and personal feelings of being motivated (#23/+4). They were also distinguished from other viewpoints by engaging in actions that developed their professional competence (#9/+3, D) and challenged themselves to reach their full potential (#31/+3, D*). As one wrote, "Feeling motivated and enjoying what I study is quite important to me, and it helps me to keep studying when courses become difficult."

Unlike respondents from Viewpoint 1, Viewpoint 2 participants pointed out the contributions of external aspects to their academic well-being. They were distinguished from other viewpoints by emphasizing the importance of the physical learning environment for their academic well-being. They needed to feel comfortable in this environment (#13/+2) and have access to needed resources (literature, databases, software, library services, etc.) (#14/+2, D).

While communication with instructors and supervisors (#27/+1, D) was valued by Viewpoint 2 participants, communication with teammates (#3/–3), family (#5/–3), and friends outside their study (#20/–3) was identified as irrelevant sources to their academic well-being. According to these participants, these aspects were neither important nor helpful for academic learning and well-being.

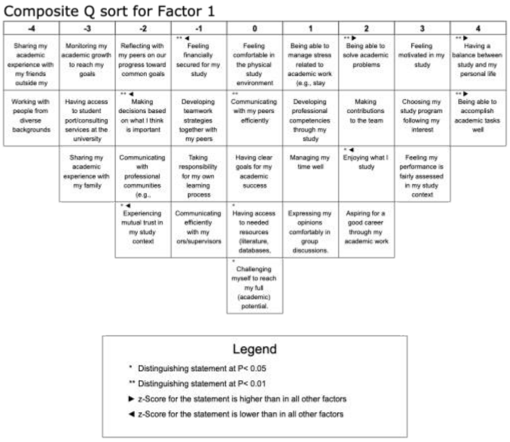

Fig. 1. The Q sort for Factor 1

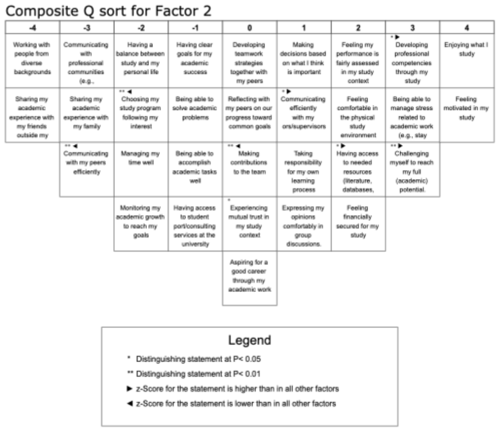

Fig. 2. The Q sort for Factor 2

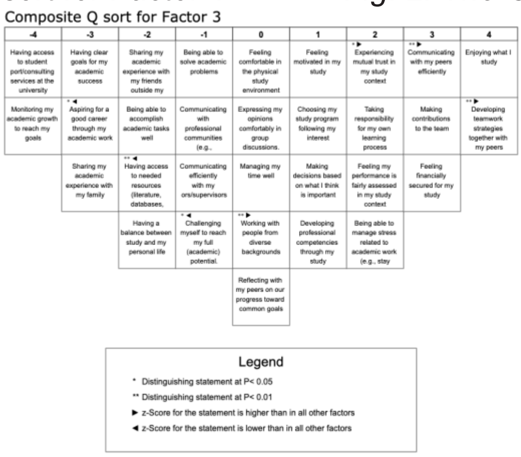

Fig. 3. The Q sort for Factor 3

4.3 Viewpoint 3 –Peer learning in project team

Viewpoint 3, explaining 13% of the opinion variance, contains two male students. In contrast with the other factors, participants in this group highly valued the external support from teamwork and peers to foster their academic well-being. Specifically, they highly ranked four statements relating to teamwork, including developing teamwork strategies together with peers (#6/+4, D*), communicating with peers efficiently (#3/+3, D*), making contributions to the team (#8/+3), and experiencing mutual trust in the study context (#15/+2, D). While participants in other groups identified working with people from diverse backgrounds as the least relevant source, participants in Viewpoint 3 ranked this statement as a positive source.

Although these external sources related to teamwork and peer support were highly valued, other external sources of support from the learning environment were ranked low by Viewpoint 3 participants. They devalued the need for having access to needed resources (#14/–2, D*) and receiving student support/consulting services at the university (#16/–4)for their academic well-being. Accordingly, they emphasized the importance of the immediate learning environment over the broader institutional environment.

In the domain of internal aspects/sources, similar to Viewpoint 2 participants, students in this group also emphasized the enjoyment of study (#21/+4), making decisions (#8/+3), and taking responsibility for their learning process (#29/+2) which may be related to their teamwork environment. However, different from students in other groups, internal sources related to agentic actions were assigned less relevance to their academic well-being, including developing academic competence (#1/−1; #2/−2), aspiring for a good career through their academic work (#25/−3, D), and challenging themselves to reach their potential (#31/−1, D). They did not value setting goals (#4/−3; #28/−4) as a highly relevant source to support their academic well-being, as explained by one student: “I don’t care much about my academic goals. Sometimes it only makes me feel stressed.”

In sum, in terms of sources contributing to academic well-being, Viewpoint 3 participants valued intrinsic motivation (e.g. enjoyment and autonomy) more than extrinsic motivation (e.g. expectations of a good career and competence development). In the domain of external sources, they highlighted the support from peers and teamwork, while contributions of the broader learning environment to their academic well-being were limited.

4.4 Consensus Statements

Several consensus statements were identified among the three viewpoints, as shown in Table 3. In the domain of internal sources, students in the three groups agreed that monitoring their academic growth to reach their goals was an irrelevant source for their academic well-being. In the domain of external sources, their feelings of being fairly assessed in the study context were ranked high among all three groups, indicating the importance of assessment procedures for academic well-being. Furthermore, two statements related to communication with professional communities and families were both identified as irrelevant sources to academic well-being. For one, engineering students in their first two years of study have not yet established relationships and networks with professional communities, while becoming independent from family relationships may be a typical happenstance in the transition to the university context.

No.	Statement	F1 Q-SV	F1 Z-score	F2 Q-SV	F2 Z-score	F3 Q-SV	F3 Z-score
5*	Communicating with professional communities (e.g., industry, companies, associations)	-2	-0,819	-3	-1,307	-1	-0,477
7*	Reflecting with my peers on our progress toward common goals	-2	-0,551	0	0	0	-0,159
9	Developing professional competencies through my study	1	0,510	3	1,310	1	0,160
11*	Feeling my performance is fairly assessed in my study context	3	1,048	2	0,871	2	0,819
13*	Feeling comfortable in the physical study environment	0	0,416	2	0,871	0	0
20*	Sharing my academic experience with my family	-3	-1,987	-3	-1,307	-3	-1,296
23	Feeling motivated in my study	3	1,077	4	1,740	1	0,810
24	Being able to manage stress related to academic work (e.g., stay calm during exams, work towards deadlines, etc.)	1	0,520	3	1,310	2	0,819
27	Communicating efficiently with my instructors/supervisors	-1	-0,470	1	0,440	-1	-0,650
28*	Monitoring my academic growth to reach my goals	-3	-1,090	-2	-0,871	-4	-1,638
30*	Expressing my opinions comfortably in group discussions.	1	0,447	1	0,436	0	0

Table 3. Consensus Statements

** All Listed Statements are Non-Significant at p<0.01, and Those Flagged with an * are also Non-Significant at p<0.05)*

5 DISCUSSION AND CONCLUSION

This paper illustrates various engineering students' perspectives of supportive sources for their academic well-being in a PBL context. While many participants valued the support of internal sources for fostering their academic well-being (Stanton et al. 2016; Trolian et al. 2022), others emphasized the contributions of external sources, such as peer support and teamwork (Schmidt and Hansson 2018; Trolian et al. 2022). Based on the findings, this study highlighted the importance of educators and universities to provide students with various sources when designing the curriculum, which enables them to choose and use these available sources based on their subjectivities to foster their academic well-being (Trolian et al. 2022). As a pilot study, one limitation of this study is the small sample size. The results only reflected 13 participants' viewpoints, while students who were not involved in this study might have different opinions. Future studies will be conducted with more participants and in different learning environments for a wider representation of viewpoints on sources of academic well-being.

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DESCRIPTIONS OF PEER MENTORS AS TOLD BY UNDERGRADUATE ENGINEERING STUDENT MENTEES (RESEARCH PAPER)

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ABSTRACT

Peer mentorship is a relationship between two people who are at a similar level. In this study, the setting is academic, namely peer mentorship amongst undergraduate engineering students. Within peer mentorship, participants aim to help one another through various activities, such as sharing information, helping motivate, providing advice, lending support, etc. The outcomes of peer mentorship are generally positive and mutually beneficial for mentors and mentees, but the focus of peer mentoring research in undergraduate engineering has primarily been focused on implementing and evaluating formalized peer mentoring efforts, not necessarily on the needs of students who may be in these relationships. To better understand students' perceptions, students at a western institution in the United States were surveyed during Fall 2020, early in the COVID-19 pandemic.

Of the 223 completed student survey responses, 79 indicated that they currently had a peer mentor when provided a definition and examples of peer mentorship. These 79 students were asked to describe their peer mentor both in terms of attributes (e.g., race, gender identity, year in school, first generational status, and major) and characteristics (e.g., enjoyment of engineering, value placed on engineering, career interests, extracurricular interests, hobbies, and effort exerted in engineering). Analysis of these student descriptions can provide recommendations of what may be important to students when finding their own peer mentors or peer mentoring advisors when attempting to formally match mentors to mentees.

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1 INTRODUCTION

1.1 Form and Function of Mentorship

In the past 20 years, the definition of mentoring has turned from the perception of mentoring being largely transactional and unidirectional with the mentor being thought of to steer the relationship and bestow information, an apprenticeship of sorts, toward more of a mentorship where the relationship between the mentor and mentee are more of a focus, meaning the mentor and mentee are helping each other in a reciprocal and mutually beneficial way (National Academies of Sciences Engineering and Medicine 2019). The types of mentorships acknowledged and observed now can include many different structures and developments; for example, a single mentor working with a single mentee formed from a formal assignment at work, a group of mentors with a single mentee formed by friendship and networking, online peer communities formed through an organization, etc. (National Academies of Sciences Engineering and Medicine 2019). Regardless of the mentorship dynamics and formation, the perspective is now that both the mentor and mentee play a role in the psychosocial and career support of one another.

With this shift in the scope of what is considered mentorship, the benefits of peer mentorship have been increasingly recognized. Peer mentorship includes a relationship between two people who are at the same or nearly the same level of experience where they are helping one another in their development (Colvin and Ashman 2010). This development, similarly to traditional mentorship, is aimed at psychosocial and career development (Collier 2017; National Academies of Sciences Engineering and Medicine 2019). In the context of this paper, this will be undergraduate engineering students at a western institution of the United States that are involved in peer mentorship to support one another psychosocially and in their academic career. Peer mentors may serve as a: (1) connecting link between their mentee and their university; (2) peer leader in motivating to do well academically and to be involved; (3) learning coach in improving personally and academically; (4) student advocate in listening and being a helper; and (5) trusted friend in connecting and caring (Colvin and Ashman 2010). Peer mentorship can provide powerful outcomes for both mentors and mentees in spaces such as identity development, increased productivity, belonging, degree attainment, achievement, satisfaction, and retention, which can be especially important for minoritized populations (National Academies of Sciences Engineering and Medicine 2019).

1.2 Matching Mentors and Mentees

One of the six practices for effective mentoring as recommended by The National Mentoring Partnership is matching and initiating (Garringer et al. 2015). Matching and initiating is creating mentoring relationships through pairings or groupings, and then supporting in the beginning of the relationship (Garringer et al. 2015). This requires decisions about how to best pair mentors and mentees as well as arranging the initial meeting(s) of the mentor and mentee (Garringer et al. 2015). When considering the dynamics between mentors and mentees, similarities and differences in their deep and surface level identities are the two primary considerations. Surface-level identities would be considered attributes that may easily determinable such as age, gender, race, etc. (National Academies of Sciences Engineering and Medicine 2019). Deep-level identities would be considered personalities, goals, attitudes, interests, etc. (National Academies of Sciences Engineering and Medicine 2019). Blake-Beard et al. (Blake-Beard et al. 2011) found that even though STEMM students perceived that having a mentor of the same gender or race would be somewhat important and they reported receiving more help from those of their own gender or race, academic outcomes, efficacy, and confidence were not any different between mentorships of those of the same race or gender and those who were a different race or gender. This is also in line with the research review of The National Mentoring Partnership (Garringer et al. 2015). However, there may be a level of interpersonal comfort and confidence that could come through role modelling by having someone of the same gender and/or race as a mentor, so considering these surface-level similarities in matching are still suggested (National Academies of Sciences Engineering and Medicine 2019; Garringer et al. 2015). Within this study, mentees share their description of their peer mentor(s) through both surface- and deep-level similarities and differences, which will be expanded upon more below.

2 METHODOLOGY

2.1 Instrument & Rationale

The research instrument used in this study is described in terms of its validity, content, and administration are found in Christensen (Christensen 2021). The exploratory mixed-methods instrument that was created and employed to determine students' needs regarding peer mentorship (Christensen 2021).

After providing consent to participate in the study, students were given a definition and example of undergraduate engineering peer mentorship. They were then asked to provide whether they currently had a peer mentor or not, also indicating if this peer mentor was within the same institution and/or engineering or not (Christensen 2021, 258–59). The students were presented an additional block of questions depending on whether they had a peer mentor or not. The analysis in this paper was focused on one of the questions posted to those who did indicate they had a peer mentor, which was as follows (Christensen 2021, 246–47):

> You indicated that you currently have a peer mentor. **Please describe who your peer mentor is.**
>
> This can include both **attributes** (i.e., race, gender identity, year in school, first generational status, and major) as well as **characteristics** (i.e., enjoyment of engineering, value placed on engineering, career interests, extracurricular interests, hobbies, and effort exerted in engineering).

It is noted that these definitions of attributes and characteristics may be interpreted differently depending on the context, but for the sake of this study, the definition that was constructed and provided to the intercoder agreement team is that an attribute is something used as a symbol of particular person, office, or status. A characteristic was defined as something representing values or qualities of a particular person. This is also the reason examples were given to students of attributes and characteristics that would fall under each.

2.2 Research Question

By having students describe their peer mentor in terms of both attributes and characteristics, student preferences for a mentor may be explored when matching mentors and mentees. To determine the prioritization of the separate attributes and characteristics that came up in student responses, the research question for this study was, “What are the self-described characteristics and attributes of peer mentors as told by mentees?”

2.3 Recruitment

All IRB approval, recruitment, and survey participation procedures are described in Christensen (2021). When asked “Do you currently have a peer mentor?”, 79 participants responded “yes”. Only 1 (1.2%) of those 79 respondents left their response blank for the question of interest. The demographic information for the 79 participants was considered representative of averages in the United States and more specifically the university the study was conducted at (Christensen 2021; Christensen and Villanueva Alarcón 2022a; 2022b). Specific demographic information for the 79 participants who did have a peer mentor as well as the entire 223 participants who submitted complete responses can be found in (Christensen 2021; Christensen and Villanueva Alarcón 2022a; 2022b).

2.4 Research Team Positionality

The positionality of the research team as well as efforts to keep the interpretation bias-free are described in all previous publications surrounding this same instrument (Christensen and Villanueva Alarcón 2022a; 2022b; Christensen, Villanueva Alarcón, and Corrigan 2023; Christensen 2021) and were employed also in this study. The first author’s position has shifted from that as a role of insider earlier publications to that of an outsider (Herr and Anderson 2015) since she is no longer a student at the institution of interest and is now an assistant professor in a different undergraduate engineering program. The second author continues to provide expertise in the realms of mentorship, teaching, and research to support analysis related to peer mentorship.

2.5 Qualitative Analysis Procedures

The goal of the qualitative analysis of student descriptions of the characteristics and attributes of their peer mentor was to find what may be most identified by students. As such, a phenomenological-approach was employed, similar to the other studies conducted by Christensen (Christensen, Villanueva Alarcón, and Corrigan 2023; Christensen and Villanueva Alarcón 2022b; 2022a; Christensen 2021) with some differences in coding procedures.

For the first round of coding, the first author randomly chose 40 of the 79 participant responses to perform initial coding using the coding system of two codes: characteristics and attributes. The definitions and examples were provided to another researcher as a code book for intercoder agreement. Provisional (i.e., coding starting with set codes with flexibility to add, subtract, or expand) and simultaneous coding (i.e., applying two or more codes to same participant response) (Saldaña 2013). Based on the two researchers' coding experiences, it was decided that sub-codes were needed to deepen the analysis.

Sub-coding (i.e., detailing data into categories) was employed in the second round of coding (Saldaña 2013). The provisional subcodes were the examples given to students for attributes and characteristics, but additional subcodes allowed emergence of other codes throughout the analysis. The first author performed this additional round of coding then approved it through the student researcher who supported intercoder agreement. Consensus was gained on the coding applied to student responses. As such, the first author was then able to apply the newly established and agreed upon coding scheme to all 79 participant responses. The sub-codes were only applied once for each participant's response even though they may have mentioned something within that code multiple times for a peer mentor or they mentioned something for more than one mentor.

3 RESULTS & DISCUSSION

The finalized coding categories with sub-codes, which include but are not limited to the examples given to students in the definition, are presented in Table 1 with frequency counts for each. Of the 404 total codes, 48% of the codes were within the realm of attributes and 52% were within characteristics. It should be noted that these codes relate to any mention of these attributes or characteristics with no regard do whether it was a positive or negative mention of that given attribute or characteristic.

Based on these results, it is shown that the five examples of attributes given in the definition to students were within the top six most frequent attributes coded with first generational status being the least frequent (i.e., 7.6% of participant responses). This is somewhat expected since major, year in school, gender identity, and race may be more easily distinguished through common conversation and appearances than first generation status. The unexpected answer within the top six attributes was courses. Courses were mentioned in 36.7% of participant descriptions, which included both being students in the same course or having a teaching assistant who became a peer mentor within a course.

The six examples given in the definition to students were within the top eight most frequent attributes coded. The ability of the student to provide quality advice and/or support to students, which was an emergent code separate from the examples provided to students, appeared with the same frequency (i.e., 36.7% of participant responses) as effort exerted in engineering. Career interests appeared in 30.4% of participant responses. "Friend" was another emergent code in the top characteristics that appeared in 10.9% of student responses. Hobbies, extracurricular interests, value placed on engineering, and enjoyment of engineering all appeared in less than 25% of student responses.

Table 1. Coding scheme for qualitative analysis with main codes (i.e., attributes and characteristics) and sub-codes as listed with frequencies.

Attributes (main code)		**Characteristics (main code)**			
Sub-code	**Freq.**	**Sub-code**	**Freq.**	**Sub-code**	**Freq.**
major*	49	advice/support	29	intelligence	4
year in school*	44	effort*	29	motivation	3
gender identity*	34	career interests*	24	formally assigned	2
courses	29	friend	23	informally assigned	2
race*	24	hobbies*	19	interests	2
first generation*	6	extracurricular interests*	14	time demands	2
marital status	2	values*	14	respect	1
religion	2	enjoyment of engineering*	13		
socioeconomic status	2	personality	10		
stage of life	1	relation/living situation	10		
transfer status	1	study group	9		
Total Attributes	194			**Total Characteristics**	210

Note: *indicates examples given to students in question prompt definition

To better visualize the overall magnitude of these sub-codes, a word cloud was generated ("Free Word Cloud Generator" 2021). It should be noted that some sub-codes were shortened or hyphenated to allow phrases to be included without being overly burdensome.

Figure 1. Cloud map emphasizing the magnitude of each coding category given according to the size of text ("Free Word Cloud Generator" 2021).

Three overarching themes that the coders garnered from this analysis is that students are going to lean toward some sense of convenience, which may come from someone they already spend time with (e.g., in the same courses and/or major, friends, relation/living situation closeness [roommate/fiancé], study group). This also allows a mutual benefit to be acquired in the relationship, which is appreciated by students. An additional theme is that students may not recognize that mentorship is happening or its power. Finally, someone with strong motivation, effort, and goals (e.g., major, effort, career interests) seemed to resonate strongly with peer mentees. Representative quotes for each of these themes are shown in Table 2.

Table 2. Representative Quotes of Themes. All

Theme	Representative Quotes
Sense of Convenience and Desire for Mutual Benefit	• "We are both super busy and don't have as much time to commit to engineering stuff, but together with our limited time we are still able to accomplish a lot. We have different hobbies and different career interests, but she is literally the only reason I have survived one of my classes this semester." (Participant 5) • "He is majoring in computer science and is as far along as I am. I am minoring in computer science so we have a lot of the same classes. I also help him with math a lot because I am farther ahead than he is in math. We have similar career interests and hobbies. We play video games together and have started our own business together. He tries very hard in his degree it's harder for him to understand certain subjects than it is for me, so I am able to help him with a lot of things." (Participant 69) • "There is a girl in my engineering class that I have grown close with. We have become friends and awesome study partners. She excels at somethings that I am not good at and I excel at somethings that she is not good at. Overall we help each other understand what is going on in all of our classes." (Participant 30).
Lack of Recognition of Mentorship	• "My peer mentor is a man I have had a large amount of classes with as our degree plans are almost identical. He is someone that I have spent large amounts of time with working on various assignments and problems within our classes that we share. Outside of our engineering interactions there is not much. We are friends, but with the amount of time we both spend on school it is ends up becoming the focal point of everyone of our interactions. I personally see nothing wrong with this as it has been incredibly constructive for me and hopefully for him as well. We do joke around and have casual conversation, but we mostly motivate one another to excel within our respective field." (Participant 8) • "I have never had an assigned peer mentor, but I feel like every semester I make a friend or two that I have a bunch of classes with and they really fill that role. Though I'm friends with a lot of the guys and have a few that I would consider peer mentors, the women I've met in engineering have helped me more than anything! They're usually at the same point as me, sometimes in my major sometimes not and even though we don't always have similar career goals or interests we always have a similar passion for engineering." (Participant 53)
Strong (e.g., motivation, goals, effort) Students Resonate with Mentees	• "She works really hard and takes school seriously so I know that she knows her stuff and will give me quality advice, not just the first thing that comes to her mind." (Participant 6) • "I have a few friends in my study group I consider to be mentors. They are all smarter than me, but still good friends. There is about half females in the study group, and I am better friends with them than the males. They all are devoted to their families, and most have spouses and a few have children." (Participant 32)

3.1 Recommendations & Implications

Based on the aforementioned results, there are a few recommendations and implementations to be recognized regarding peer mentorship. For the first theme of students leaning toward some sense of convenience for who their mentor is, mentees valued the mutuality of benefit in the relationship, particularly around interest convergence. This is an important theme as we didn't recognize a strong need of race or gender being central to mentor/mentee matching conveyed by students even though they may have mentioned the race or gender of their mentor. Interest convergences amongst departments of engineering can be centralized around not just technical aspects (e.g., engineering clubs, professional societies, etc.), but they can also be centered around personal interests (e.g., sports, arts, video games, etc.) to be able to conveniently connect students. For this, it is recommended that engineering departments try to intentionally coordinate events with centralized campus entities to bring together engineering groups to that. While many of these personal connections can happen organically, there does appear to be value provided in formalizing some of these initiatives at the department and institutional levels.

There is a level of mutual reciprocity that can come through these peer relationships. It does not necessarily matter that one student is stronger academically or more involved extracurricularly. It does not necessarily matter that students are the same major or at the same point in their academic career. It should be continually emphasized that together, mentors and mentees can accomplish more because no one person is able to know or do everything.

Second, students may not recognize all the mentorship that is happening since they may only have casual or very compartmentalized connections to these mentors with a lack of formalization, but they do recognize the significance of these relationships. A recommendation for this theme is to intentionally bring forth knowledge from upper-level students to students in lower-levels to share knowledge and insight regularly. For example, bringing in students as both peer mentors and undergraduate teaching assistance may allow students to more regularly identify mentors who can help them navigate their educational processes with more ease. Another example can be an assignment created by an instructor where students are tasked to interview upperclassmen with the intent to help them navigate their class or overall undergraduate research experience. While these activities may appear simplistic, these examples highlight that these types of organic connections do not require many resources to make large impacts on students' success.

Students may need help in recognizing and capitalizing on these relationships. As mentioned by participant 8, it can be "incredibly constructive" to have a mentor, even if you may not interact with them in all spaces. When considering matching mentors and mentees, it may be advantageous to allow for choice and matching to happen in various spaces, allowing students to find someone who can help them in one specific area as needed without the expectation that they need to just have a single mentor that can do everything. Advising can also play a role in this, whether formal academic advisors or faculty advisors and mentors, to encourage and help in networking efforts.

Lastly, there is a sense that there is a benefit to having a strongly motivated and intelligent peer mentor. Students really focus on the support and advice that can be given by their peer mentor, which may be a result of who the mentor is as a person and what they value. These things should be considered if formally matching mentors and mentees.

As these considerations are made in our development of a culture of peer mentoring either through formal or informal needs, we can see that there is a need for certain characteristics and attributes to be considered depending on the needs of both the mentor and mentee. As we better consider this matching in a flexible way, students can continually find and benefit from a variety of mentors instead of getting focused on just one mentor who is the lone source of all support.

3.2 Limitations & Future Work

This survey was given under COVID-19 pandemic circumstances, so it is recognized that this may have influenced student responses. There were limitations to the short-answer, anonymous format of the question analyzed since it was very limited in the scope it was able to cover. With students being offered definitions of attributes and characteristics, obviously those were some of the top codes, but we did see that students emerged with other characteristics and attributes that were important to them in highlighting the description of their peer mentor. Because of the format, the research team could not further ask for elaboration or clarification in areas of interest. The responses also were not considered in conjunction with any participant demographic information or other responses to qualitative questions. Future work could allow these combinations of results to be further pursued. Future work will also explore additional insights about the needs and perceptions of those with a peer mentor versus those who did not have a peer mentor.

4 CONCLUSION

By exploring descriptions of peer mentors from those students who currently felt that they had a peer mentor allowed for the emergence of things that should be considered when matching, initiating, and encouraging mentorships. Students really resonate when there is a mutual reciprocity in their relationships, allowing themselves to receive support but also to give support. Students may also have difficulty in recognizing the importance of the mentoring relationships they do have, regardless of how casual they may seem. Students also appreciate when their mentors show strong motivation, drive, and value, which helps them to push themselves as well. These findings further confirm the benefits of peer mentorship and the wide variety of positive means that peer mentorship can come by. This speaks to the need for students to have many mentors for the various spaces they are involved in and have choice and flexibility in their mentors. Students do not need to be the “same”, but any positive connections created for students are meaningful.

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TIME TO RETHINK ENGINEERING OUTREACH?

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ABSTRACT

Starting with the research question 'Does engineering outreach work?' this paper looks at the often 'sticky' subject of the validity of engineering outreach in UK High Schools. It examines how Engineering Outreach Activities are conceptualised by external bodies (RAEng., 2016) and critiques the complex range of practical experiential engineering educational interventions offered in school (Neon, 2023, STEM learning, 2023). Drawing upon the findings of, what is, a small single strand of a much larger multi-method, longitudinal analysis of Engineering Education Outreach Activities provided across the West Midlands region of the UK (LBEEP, 2023)], the paper provides a unique insight and descriptive analysis of engineering outreach in schools.

The findings section comprises a comparative analysis of the socio-economic background of schools before looking at the gender breakdown of outreach participants. The various engineering interventions provided are briefly discussed before consideration is given as to how sustainable current engineering outreach activities are. Finally, in questioning whether the UK's current approach of providing engineering education experiences in the form of what are often idiosyncratic, short-term episodic activities, the paper questions the financial, pedagogic and practical wisdom of confining engineering education to 'outreach'. The conclusion suggests that it's time for a sea-change in how we, as a society, teach children and young people about engineering and suggests that perhaps it is time to embed the subject into more established areas of study such as maths and science but also in history and social science.

1. **INTRODUCTION**

Launched during an unprecedented time in UK (and indeed global) history, the Lord Bhattacharyya Engineering Education Outreach Programme (LBEEP) kicked off at the beginning during the Autumn term of 2020. Midway through a series of 'lockdowns,' the Covid19 Pandemic wreaked havoc across society, resulting in a two-year period whereupon home schooling and working became the norm for many. As few children physically attended school during this time, parents became teachers and teachers were forced to reconceptualize how and what was taught. This had a notable impact on LBEEP. Originally planned to last for five years, to say that the first half of the outreach activities were 'interrupted' by Covid19, would be an understatement. Yet, LBEEP continued. Engineering Education activities were offered during the short periods of time when lockdown was lifted and, in some cases, 'home schooling' activities were offered. This discussion paper reflects upon almost three years of *outreach* activities. Setting the wider context before briefly comparing different activities and considering the sustainability of engineering outreach as part of what schools offer.

2. THE LBEEP ENGINEERING EDUCATION OUTREACH PROGRAMME: WHAT IS PROVIDED TO WHOM?

Located in the West Midlands region of the UK, LBEEP is provided in an area where there are 2,726 Secondary Level Education Institutions. In the region, there are 14 different Local Authorities that are currently responsible for educating 971,332 pupils aged 11-18 years. A socially and culturally diverse area, schools were selected to participate in LBEEP on the basis of the percentage of pupils from higher-than-average number of children from poorer socio-economic backgrounds. One key indicator used in the UK to measure socio-economic background is the percentage of children in receipt of free school meals (FSM). Across England, an average of 22.9% of pupils receive FSM. In the wider West Midlands this figure is 24.4%; whereas in the areas where LBEEP schools are located it is 29.9% (Fig 1).

Figure 1: Local Authorities of the Wider West Midlands Region: Pupils receiving free-school meals (FSM) by gender.

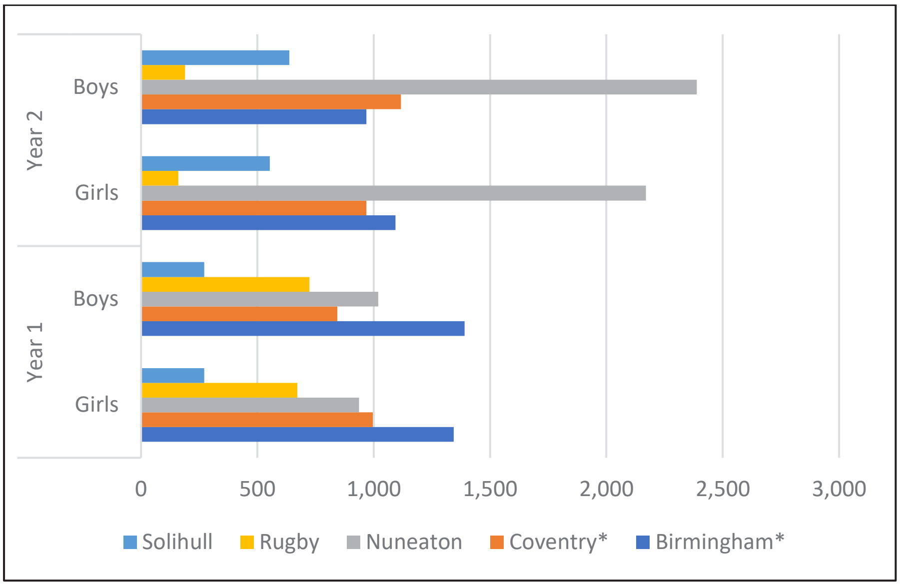
			Number of Pupils			
Local Authority	Number of EIs	Average Percentage FSM	Boys	Girls	All	Percentage of Total
Birmingham*	520	35.2%	107,802	104,327	212,129	21.8%
Coventry*	130	25.4%	30,950	29,684	60,634	6.2%
Dudley	117	25.7%	24,008	22,353	46,361	4.8%
Herefordshire	113	15.2%	12,955	11,858	24,813	2.6%
Sandwell	130	30.1%	31,729	29,613	61,342	6.3%
Shropshire	186	14.2%	22,636	21,864	44,500	4.6%
Solihull*	89	23.0%	20,897	19,672	40,569	4.2%
Staffordshire	446	17.7%	62,898	59,958	122,856	12.6%
Stoke-on-Trent	108	31.8%	20,703	20,407	41,110	4.2%
Telford and Wrekin	85	24.4%	16,636	15,656	32,292	3.3%
Walsall	130	33.0%	27,962	26,764	54,726	5.6%
Warwickshire*	278	17.6%	46,713	44,991	91,704	9.4%
Wolverhampton	121	37.0%	24,944	24,685	49,629	5.1%
Worcestershire	273	18.0%	45,298	43,369	88,667	9.1%
Total	2,726	24.5%	496,131	475,201	971,332	100.0%

*Areas where LBEEP Schools are located

2.1 LBEEP Participating Students: Gender & Geographic Area

Now in its third year, LBEEP has provided a range of outreach activities to high school pupils within its catchment area since September 2020. Whilst participating schools were originally selected before the project began, the numbers of pupils taking part in LBEEP activities varies from year to year. In the first year of the project Birmingham attracted participation from the highest numbers of female and male pupils, in year 2 it was Nuneaton. This is shown below in Figure 2

Figure 2: Geographic Spread of LBEEP & Gender of Participants



2.2 Engineering Focus of LBEEP Activities

LBEEP schools applied for funding to provide numerous engineering-focused learning activities, with Aero-Astro Engineering proving to be the most popular in the first two years of the programme. Perhaps not surprisingly, given the geographic location of the West Midlands, Vehicular & Electro-Electric Engineering also proved popular. Figure 3 shows the number of successful funding applications per activity.

Figure 3: Type of Engineering Covered by LBEEP 2020 / 21 & 2021-2022 (Excluding General Engineering)

	2020-2021	2021-2022
Aero-Astro	10	12
Computing – Robotics	8	6
Civil Construction	4	3
Electrics – Electronics	9	9
Environment & Sustainability	5	4
Manufacturing and design	8	5
Mechanical Engineering	9	3
Vehicles	8	9
Other	9	7

It is important to note that the above displays numbers relating to funding applications in relation to individual schools. In many instances a school applied for funding for several projects, often in the same area of engineering. The number of individual projects offered are better displayed below in Figure 4 as part of the discussion about sustainability which looks at the nature of projects as opposed to the type of engineering funding was applied for.

3. DISCUSSION: IS ENGINEERING OUTREACH SUSTAINABLE?

The importance of providing sustainable engineering outreach activities comes to the fore when examining the numbers of university students studying STEM subjects in general and engineering in particular (Smith et al., 2022). Figure 4 provides an insight into the number of engineering outreach activities offered per year across the programme in terms of sustainability. Column 2 provides an insight into the potential sustainability afforded provided by the activities funded, whilst columns 3, 4, & 5 indicate how many activities were funded in each area per operational year. In classifying the below, the sustainability of activities was classified thus: Socially Sustainable [S] – such projects include sustainability from an educational sense: Economically Sustainable (E): Environmentally Sustainable (Ev).

Figure 4: The Sustainability of LBEEP Funding

	Sustainability	Yr 1	Yr 2	Yr 3
Capital investment	High levels of [E] [S]. Limited [Ev] depending on the nature of individual project	30	30	26
Competition	Limited [Ev] in some – depending on nature of competition. Lacking sustainability in other areas due to necessarily high attrition rates – competitions based on winners at each stage.	17	18	16
STEM club	Limited [S] [E] [Ev] – due to low numbers of participants in individual STEM clubs (tendency to be exclusive)	15	13	10
General curriculum	Capacity for high levels of [S] [E] [Ev] in all areas where funding focused on curricular enhancement.	7	18	8
Externally provided workshop	Little or no sustainability due to bespoke and episodic nature of events	11	7	4
Visit	Little or no sustainability due to bespoke and episodic nature of visit	4	9	2
External talk	Little or no sustainability due to bespoke and episodic nature of talk	2	1	1
Total		54	69	33

This brief insight into engineering outreach encapsulates schools whose student body comprises a higher-than-average percentage of pupils living in socio-economic deprivation (evidenced in Fig 1 showing the percentage in receipt of FSM). This not only makes the need for a sustainable approach to be offered in terms of the future employability of pupils (i.e., Social Sustainability) but also makes the need for the funding to be spent wisely with the needs of future cohorts of children equally as important as those currently enrolled (Social and Economic Sustainability). An analysis of LBEEP applications identified a high number of requests to purchase equipment that can be re-used. This included a range of engineering education 'kits', 3D printers and computer tablets (the numbers per year are given in row 2 'Capital Investment'. Investing in equipment which can be reused on a longer-term basis suggests a commitment to longer-term engineering education, indicating that many of the schools adopted a sustainable approach to LBEEP.

In addition to purchasing equipment, a relatively number of the schools entered pupils in ‘STEM’ competitions, with almost half of the applications in year 3 relating to such activities. As competitions tend to be time-limited, often focused upon a single event or experience, such projects tend to be less sustainable. Indeed, the very nature of a school competition inevitably results in high numbers of ‘attrition’ (dropouts) at each stage – possibly turning children ‘off’ engineering for good?

Funding for STEM clubs, which generally attracted lower numbers of pupils account for between one-fifth and just under a third of funding applications across the three years of the project. Whilst sustainable in the sense of continual provision and potential long-term impact on participating pupils, the small numbers of pupils who engage with STEM clubs means that such activities lack social and economic sustainability.

Finally, funding for single visits to local museums and other places of interest such as car manufacturers also necessarily involved a single event as did external funded talks. Again, the sustainability of these activities, in terms of the longer-term impact on young peoples’ perceptions and subsequent life and education choices is difficult to determine.

4. CONCLUSION AND RECOMMENDATIONS

This descriptive conceptual paper refers to a small piece of work that is very much an ongoing strand of a much larger project. Concurrently, two PhD theses are exploring the educational impact of engineering outreach. One of the major challenges faced by this programme of outreach is that it started at the same time as the unforeseen Covid19 Pandemic brought the country (and globe) to a standstill. Despite causing unprecedented change to how education was provided over a period of at least 2 years, the research findings thus far suggest that teachers tried their hardest to find a way of providing outreach even when most pupils were being home educated.

In conclusion, the emerging findings from this small study indicate that there is a need for the engineering outreach activities offered under the auspice of LBEEP to continue. However, taking account of the findings and considering broader debates in this area it is not unreasonable to postulate that it may be time for *a sea-change in how we, as a society, teach children and young people about engineering.* Engineering Outreach, even a large programme such as LBEEP can only ever ‘scratch the surface’ – excluding more pupils than including them.

One important emerging recommendation is that the LBEEP programme be extended to include primary schools. This would enable children to gain some insights into engineering and applied science before they move to high school, hopefully sparking their engineering imaginations a few years ahead of the time when they are forced to select their GCSE options (currently around age 14 years). Moreover, there is little doubt that *it is time for secondary and primary education to embed engineering into the more established areas of study such as maths and science but also in history and social science.* This would enable children to become aware of the important role played across all areas of society by engineering, whilst providing the means by which engineering imaginations can be sparked at an early age!

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AN EMBEDDED INTERVENTION TO SUPPORT THE DEVELOPMENT OF STUDENT FEEDBACK LITERACY

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ABSTRACT

Feedback literacy is an emerging concept. It is seen as an individual competency that facilitates taking an active role in contemporary feedback processes. As such, it is a valuable skill not only in the classroom, but also in students' future professional lives. This paper reports on a qualitative study of a learning intervention embedded in a lab series, aimed at developing first-year engineering students' feedback literacy. The intervention consists of a short e-learning module, a one-hour workshop, and two peer feedback assignments. The design of this interventional study is based on the comparison of an experimental group with a control group. Both groups participated in focus group discussions after the intervention (n=55). Findings were complemented by data from reflection logs collected at the end of the semester describing students' most important feedback experience (n=42). The results suggest that the learning intervention contributed to the understanding of the key concepts and principles of feedback literacy. Moreover, students in the intervention group appear to value their peers better and recognise their valuable contribution in the feedback process. Although students realise that easily applicable feedback, such as minor corrections, make a limited contribution to their learning, they still often prefer it because of the minimal time effort required. Based on the findings, the paper concludes with recommendations for both individual courses and entire programmes, such as encouraging reflection, and supporting students in storing and revisiting feedback.

1 INTRODUCTION

Over the past decade, there has been a shift in the way feedback is perceived in education. Scholars reoriented the transmission-focused view on feedback towards a learning-focused view in which students play an active role (Henderson et al. 2019; Winstone and Carless 2019; Boud and Molloy 2013; Molloy, Boud, and Henderson 2020). Feedback is thereby seen through the lens of social constructivism as a partnership between teachers, students, and peers (Thurlings et al. 2013; Winstone and Carless 2019). Engineering education also recognises this, and students must increasingly take charge and responsibility for their own learning (Diefes-Dux 2019; Jaeger and Adair 2018; Wallin and Adawi 2018). To take on the active role in the feedback processes, students need requisite skills and capacities, which has been termed 'student feedback literacy' (Sutton 2012; Carless and Boud 2018; Nieminen and Carless 2022). In their seminal paper, Carless and Boud (2018) defined student feedback literacy as "the understandings, capacities and dispositions needed to make sense of information and use it to enhance work or learning strategies" (2018, 1316). It therefore refers to the ability of students to understand and use feedback effectively in order to improve their learning. Since students' capacities partially depend on how teachers create their learning environments, the term 'teacher feedback literacy' was also defined in a similar way as "the knowledge, expertise and dispositions to design feedback processes in ways which enable student uptake of feedback and seed the development of student feedback literacy" (Carless and Winstone 2020, 4). Discussion of exemplars and engaging in peer feedback are proposed as two well-known learning activities that can be re-focused more explicitly towards developing student feedback literacy (Carless and Boud 2018). Purposeful selection and well-aligned discussions of exemplars put teachers in the lead of highlighting key aspects of quality work by clarifying the reasoning, while showing that quality is manifested in various ways (Sadler 1989; To and Carless 2016). Next, engaging in peer feedback is often more beneficial than only receiving feedback, as it involves developing evaluative judgement, both about the work of peers as about own work, which can eventually reduce the need for external feedback (Nicol, Thomson, and Breslin 2014). Therefore, this paper reports on a study in which a learning intervention containing analysis of exemplars and peer feedback was embedded in a technical lab. The aim of the intervention was to support the development of student feedback literacy. Based on reflection logs and focus group discussions, the effect of the intervention and students' general attitudes towards feedback are discussed.

2 METHODOLOGY

2.1 Participants

All freshmen from the 2022-2023 academic year of the Faculty of Engineering Technology (KU Leuven) at De Nayer Campus were considered in this study (n=66). Two lab groups (n=28) were assigned as intervention groups, while the other three lab groups (n=38) remained as control groups. A reference group was also included in the study, comprising of 67 freshmen who were enrolled in the academic year 2021-2022 in the same programme at the same campus.

2.2 Context

All freshmen involved in this study were enrolled in an integrated module. During the first weeks of the semester, professional competences are taught in full-group lectures in the auditorium. During the rest of the semester, these competences are practised in an integrated way in technical lab sessions with smaller groups. In the first semester, the focus of professional competences is on HSE (health, safety, and environment), professional communication, academic writing skills, information skills, critical reflection, and feedback literacy. As part of the topic on academic writing, the rubric that will be used to assess students' academic writing skills was explained and good and bad examples were discussed.

The lab topic that is used to test the learning intervention consists of two three-hour lab sessions, complemented with a mandatory preparation through an online prelab module, and report writing after each session. The reports must be submitted per team and are therefore a responsibility of the entire team. At the beginning of the first session, the rubric for assessing students' academic writing was briefly reviewed with students of the reference groups (academic year 2021-2022) and control groups (academic year 2022-2023). Students in the intervention groups (academic year 2022-2023) practiced the rubric more thoroughly on an exemplar, as will be described later in this paper. In academic year 2021-2022, a combination of teacher feedback and peer feedback was used with students in the reference groups. In academic year 2022-2023, the control groups received only teacher feedback, while the students in the intervention groups only engaged in peer feedback, as discussed in the section about the learning intervention.

2.3 The learning intervention

The intervention consisted of 3 main elements: (1) a short e-learning module, (2) a one-hour workshop, and (3) two peer feedback assignments, one after each lab session. Firstly, the e-learning module introduced students to the key concepts and principles of feedback literacy, including its definition by Carless and Boud (2018). As part of the module, a knowledge clip was used to highlight similarities between the technical topic of the lab and feedback processes. Secondly, a workshop was organised at the beginning of the first lab session, and students were divided in teams for the remainder of the lab topic. They discussed several introductory questions within their team, such as "What is feedback?", "What is the function of feedback?", "What effect does feedback have?" and "Where and from whom does feedback come?". After the team discussions, the questions were discussed amongst the full lab group to develop a shared definition of feedback and to link it to the feedback literacy definition by Carless and Boud (2018, 1316). To continue the group discussion on feedback literacy and bring in different angles, PollEverywhere was used so that students could anonymously "score" the feedback literacy level of ten authentic student quotes by clicking emoticons on the standard PollEv 'emotion scale'. The quotes were carefully selected from earlier collected student data. Some exemplary quotes include: (1) "*I used to think that feedback was a tool for teachers to indicate whether you are doing well or not, but actually I have come to realise that it is so much more than just a few sentences about what you are doing. I started doing more with feedback, both feedback at school level, and feedback in my personal environment. Thinking more often and longer about the feedback I get and really thinking about it. I did that much less before.*", which was selected to demonstrate a change in the student mindset and to expand the view of feedback as being limited to an educational setting; (2) "*When I receive feedback, I put it on a list. Then, when I make or revise an assignment, I keep this list alongside me and check whether I have taken into account all these aspects I have done wrong in the past. This way, I know that I am already less likely to make mistakes in this area.*", which was selected to stress the active role of the student in organising feedback so that it can be reused in the future and to discuss options on how to do so; and (3) "*About two weeks back, we received our first feedback on the report. I must admit that at first sight I was unpleasantly surprised. On reflection, I noticed that the feedback were all thoughtful and correct comments. Consequently, I felt obliged to correct these errors.*", which was selected to bring in the emotional aspect and to emphasise that it is fine to put feedback aside when it comes in hard, but that it is necessary to pick it up again afterwards for feedback to be effective. Next, the rubric for assessing academic writing was reviewed, and students practiced it using an exemplar report of the same lab topic that was specifically crafted to contain both good and bad examples. Afterwards, the strengths and weaknesses of the exemplar were discussed within the lab group. Finally, the students were instructed about the further timing of the lab series and the practicalities of the peer feedback assignment.

2.4 Data collection

At the end of the semester, two separate methods of data collection were used: (1) students wrote a reflection log, and (2) focus group discussions were organised.

Firstly, 54% of students (n=36) from the reference groups, and 64% of students (n=42) from the intervention and control groups (n=18 and n=24 respectively) submitted a reflection log through the university's portfolio system and agreed to share their data based on informed consent. In this reflection log, students used an open text field to describe a personal feedback experience that they believe contributed the most to their learning in the past semester. Students also used checkboxes to indicate some general aspects related to the feedback experience, such as the context to which the experience was linked (i.e., exercise session, exam, lab report, presentation, etc.), and who was involved in generating the feedback (i.e., teaching staff, peers, themselves, or others).

Secondly, five focus group discussions were organised with the students of the intervention and control groups. The group discussions were organised within the different lab groups, lasted 1 to 1.5 hours, and were allocated in the students' class schedule. A semi-structured format was used, where the facilitator's involvement was minimized to prompting questions and summarizing discussions to keep focus and spark further discussion amongst participants. To keep participants engaged, they were regularly asked to move within the room to take a stand regarding various statements and then explain why, such as “Would you consider yourself as active or rather passive during feedback processes.”, and “Do you pay attention to the transfer of feedback from one learning experience to another?”. In the intervention group, all students (n=28) participated and agreed to share their data based on informed consent. In the control group, 71% of students (n=27) participated in the group discussions and agreed to share their data.

2.5 Analysis

Both the data from the reflection logs and the focus group discussions were used to evaluate the effect of the learning intervention. The data from the reflection logs were mainly used as quantitative data, where the general aspects of the feedback experiences were summarized by counting the information marked through the checkboxes. The information in the open text field, further describing the feedback experience, was used as supportive qualitative data, and was analysed to see to what extend it supported the quantitative data collected through the checkboxes. Data from the focus group discussions were further used to show students’ general attitudes towards feedback. The focus group discussions were transcribed verbatim and thematically analysed using Nvivo. An inductive coding approach was used. The transcript was first read in depth multiple times while writing down initial codes, after which it was fully coded.

Ethical approval for this study was obtained from the university’s Ethics Committee (G-2020-2354 and G-2022-5693) and participants have consented to be part of this research. They were informed that their participation was voluntary, and that the analysis would be conducted anonymously. All data were collected in Dutch and translated by the first author after analysis.

3 RESULTS AND DISCUSSION

3.1 Effects of the learning intervention

The aim of the intervention was to support the development of student feedback literacy, relying on two well-known learning interventions: discussion of exemplars, and engaging in peer feedback. Since the students in the intervention groups used a rubric to assess their peers’ academic writing of lab reports, these elements were expected to be present in the students’ reflection logs. Table 1 shows an overview of the total number of reflection logs received from each group, detailing (1) the number of students who indicated the process of writing a lab report as their most important feedback experience, and (2) the number of students who indicated both the process of writing a lab report and the involvement of peers. The percentage-numbers hereby refer to the full sample size. For example, 36 reflection logs were collected from students from the reference group. From this group, 21 students (58%) wrote about a project report as being the topic of their most important feedback experience. Of the

36 students, 8 students (22%) wrote about the project report and claimed the involvement of peers in their most important feedback experience. The wording ‘peer feedback’ is explicitly not used in Table 1, as it would suggest the didactic format of using peer feedback assignments, while these reflection logs also contain references to peers outside of these structured assignments.

Table 1. Overview of the reflection logs about a project report involving peers

Academic year	**Group**	**Reflection logs (total)**	Reflection logs about a lab report	Reflection logs about a lab report and involving peers
2021-2022	reference	n=36	n=21 (58%)	n=8 (22%)
2022-2023	control	n=24	n=4 (17%)	n=2 (8%)
	intervention	n=18	n=11 (61%)	n=8 (44%)

Based on the available data, it appears that the process of writing a lab report was claimed more often as their most important feedback experience by students who were engaged in peer feedback, i.e. the students of the reference group (58%) and the students of the intervention group (61%), as opposed to the students in the control group (17%). By organising peer feedback, each individual member of the team is required to use the assessment rubric to analyse reports from other teams. The use of the rubric also emerged during the focus group discussions with the students of the control groups. Despite being discussed extensively in the full-group lecture in the auditorium, and although the submission form in the Learning Management System reminded students of the marking information and included the link to the assessment rubric, the majority of students from the control groups surprisingly commented that they did not use the rubric before submitting their reports. Since students were free to choose their most important feedback experience for their reflection log, the data suggests that engaging in peer feedback and analysing the assessment rubric contributes to students’ learning. Further research should indicate whether it subsequently also motivated students to participate in writing their team report as a joint effort, rather than allowing one student to focus on the writing.

As expected, Table 1 further shows that students in the reference and intervention groups more often claim involvement of their peers in their chosen feedback experience, 22% and 44% respectively, compared to only 8% of students in the control group. Analysis of the data in the open text fields describing the feedback experience shows that the two students in the control group describe personal interactions with peers, such as “*receiving hints on how to use specific functions in Word*” when writing reports, and “*that they had to be clearer during writing as their text was not fully clear to the own team members*”. Furthermore, although eight students of the reference group indicated peers as being part of the peer feedback process, none of them acknowledged their peers in their further description, opposed to seven out of eight students of the intervention group explicitly acknowledging peers with quotes such as “*It's great to get feedback from a fellow student and not always from a teacher,* *because fellow students sometimes look at it from a different angle and you can also learn a lot from that*", "*In doing so, fellow students help raise my level*", and "*For me, the most important feedback is the help and feedback from my fellow students.*" This suggests that the learning intervention contributed to students understanding of the value of peer feedback.

Next to that, it was observed during the focus group discussions that students from the intervention groups had a broader view of feedback. They spontaneously mentioned examples outside an educational context, such as feedback from a coach while playing sports. Even when attempts were made to elicit such contexts from students from the control groups by asking about "other situations" or prompting that they needed to "think broadly", they did not mention it until literally asked if none of them played sports. Since all students acknowledged the value of feedback from a coach while practicing sports, having a broader view of feedback and thinking of analogies outside of the educational context, could also motivate students to engage more with feedback within their programme.

3.2 General attitudes towards feedback

The focus group discussions revealed students' personal trait about openness to feedback. When asked about what they would do if they received conflicting feedback information from multiple sources, students from the intervention groups recalled their experiences with peer feedback. They initially accredited the contribution of peers with claims as "*feedback from a student is not inferior*", but also demonstrated some reluctance by statements as "*fellow students have the same knowledge as you, but okay, if they have experienced it in a different way… it might provide a different scope*". In case of conflicting feedback, students would still put teachers' feedback first because "*those are trained for that*" and "*students place less importance on it*". Where students of the intervention groups make a distinction between the level of expertise of peers and teachers, students of the control groups directed the discussions towards the influence of the accessibility of different teachers: "*there are teachers and professors with whom I can ask my questions directly, but with others I might not*", and "*in course X, for example, asking a question is a completely different situation from course Y. In course Y, you can actually hardly do that*". Overall, students from both the intervention and control groups, consent that in the end they will mainly use the feedback "*they understand the most*" or the feedback "*which is the easiest to apply*".

Most students, both in the intervention and in the control groups, showed a preference for easily applicable feedback because "*that's going to work faster as you also correct immediately without the need for reading it again*". Discussions quickly reveal that students experience a high workload within their overall curriculum: "*It requires a lot of work and time. If you want to do everything perfectly, all the steps, you will be working for a very long time. Okay, it might have an effect, but is the effect big enough to take all those steps? We also have more than just that to think about.*" and "*Usually you have so many tasks to do and then you say 'OK, I'm going to spend that morning working on that report and hopefully that will be finished'. Then, if only a limited number* *of items remain, you do it in the evening, but you usually than have to prepare another lab session, or other things, so then you have to see that you have done everything, which actually sometimes puts you under time pressure.*” Students realised that quickly working through corrective feedback makes it “*much more likely to start making those mistakes again*” by “*not thinking too long about what exactly went wrong*”, but the majority of students comforted themselves that they remember the most important aspects in future occasions.

Since most students rely on memorising their feedback, they were asked for examples of how to store feedback so that it can be retrieved afterwards. Only five students spread over the different groups claimed to have a systematic approach. The first student used a small notebook to keep notes in the past, but did so because it was mandatory for a specific course and admitted not having used it again afterwards. A second student said to check earlier assignments, but highlighted that it was also during a specific course with frequent similar technical reporting. A third student wrote down feedback on separate papers and put them with the topic to which it related so that it could be retrieved in the future. A fourth student mentioned using an Excel-sheet in which the feedback is summarized. When working on a new assignment, earlier feedback is checked to prevent making the same mistakes again. The fifth student said to make photos of the feedback with a smartphone, but immediately admitted that they often cannot be retrieved afterwards. These findings highlight the need to support students in storing feedback so that it can be easily retrieved afterwards, and to provide subsequent tasks so that students learn to reuse feedback and further appreciate the purpose of these feedback processes.

4 CONCLUSIONS

Both the analysis of the reflection logs and the focus group discussions indicate that the learning intervention contributed to the understanding of the key concepts and principles of feedback literacy. Students in the intervention groups demonstrated increased awareness of the valuable contribution that peers can make during feedback processes and showed a broader view of feedback. This indicates the importance of teacher feedback literacy in creating an effective feedback environment that helps develop students’ feedback literacy. In general, students preferred easily applied feedback because of the minimal time effort required, although they realised that it makes a limited contribution to their learning. Moreover, the majority of students comforted themselves that they will remember their feedback if needed, and only a limited number of students attempted to store and revisit their earlier feedback. Therefore, next to showing the importance of making feedback processes explicit in individual courses, this study suggests putting more emphasis on the learner's active role in relation to their own learning so that they understand that it also requires a time commitment, e.g., by encouraging reflection to get a better understanding of their actual feedback. Furthermore, it would be valuable to give students ideas on how to store and revisit feedback and reflections, e.g., by using feedback logs within a course, or by providing students with a programme-wide feedback portfolio to encourage feedback transfer.

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DO WE UNWITTINGLY EXCLUDE STUDENTS? A CASE STUDY TO EVALUATE AN ENGINEERING TEST FOR INCLUSIVITY

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***Keywords**: diversity, inclusion, engineering identity, personal preference test*

ABSTRACT

Engineering stereotypes can hinder different groups to identify with and choose for engineering. The stereotypical image, often characterised as male, white and harsh technical oriented, can negatively impact students' perception of engineering as a field to which they can belong.

Recently, PREFER tests were designed to increase students' awareness of the different roles an engineer can take on and of the importance of professional competencies in engineering. Research indicated that the tests were gender-sensitive, meaning that females had other role preferences than males. These results inspired a follow up project to investigate how the tests can be used as instruments to increase attractiveness and retention in engineering.

This paper reports on a study to evaluate whether the PREFER Explore test was designed in an inclusive way. To validate the test with different student groups, a

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survey was distributed among first year engineering students (N=802, October 2022) and final year secondary education pupils in science/math tracks (N=173, March 2023) in Belgium. After completion of the test, participants were asked eight additional questions about their experience with and perception of the test.

Small but significant differences were found in the perception of female and male students, e.g., females identified less with the test and had more difficulties selecting their preference. Students with a migration background indicated that the test strengthened their interest in engineering. The study shows that the perception of different underrepresented groups should be included when validating educational tools if we do not want to unwittingly exclude students.

1 INTRODUCTION

Due to the rapid change in technological innovation, there is a high need to increase the number of engineers in the labour market but also to increase diversity in engineering. To date, the heterogeneous society is not reflected in the engineering population. Consequently, large groups are neglected or disadvantaged by technological innovation. For example, the design of smartphones. Men can comfortably use the device one-handed, but it is harder for people smaller hands, i.e., women. Voice recognition is not helpful as voice-recognition software is often male-biased (Perez 2019). People of colour have similar problems with face recognition that is tested more with white people. It is clear that a more diverse and intersectional perspective is necessary in technological innovation. The latter is not only beneficial for the end user but also for companies. More diverse teams lead to improved problem solving, increased innovation or more accurate predictions (Hunt et al. 2018).

Engineering stereotypes are one of the factors that can hinder different groups to identify with and choose for engineering. The stereotypical image of engineers, often characterised as male, white and harsh technical oriented, can negatively impact students' perception of engineering as a field that they can belong to or fit in (Bairaktarova and Pilotte 2020; Faulkner 2007; van Veelen, Derks, and Endedijk 2019). Recently, PREFER tests were designed to increase students' awareness of the different roles an engineer can take on and of the importance of professional competencies in engineering (Carthy et al. 2019; 2022). Research indicated that the tests were gender sensitive, meaning that females had other role preferences than men (Carthy et al. 2020). These results inspired us for a follow up project to investigate how the tests can be used as instruments to increase attractiveness and retention in engineering. This paper reports about a further investigation of one of the tests, the PREFER Explore test, on how it is perceived by diverse groups of (future) engineering students.

2 BACKGROUND OF THE PREFER TESTS

The PREFER tests are based on the PREFER framework, an innovative competency based professional roles model that was validated in education and industry (Craps et al. 2021). The framework describes three roles that early career engineers can take on when entering the labour market, independent of discipline: product leadership (focusing on radical innovation and research and development), operational excellence (focusing on product or process optimisation and increasing efficiency) and customer intimacy (focusing on tailored solutions for particular customers). In practice, engineers can operate in a single role, or combine roles. In close collaboration with industry, 13 expert panels were organised to identify the most important professional (non-technical) competencies required to be successful in these roles. This resulted in a unique reflective instrument that can be used by students to get a grip on the broad field of engineering and to explore what engineering is beyond the engineering stereotypes. A study of Craps (2022) indicated that a more diverse perspective on engineering might influence the female students' confidence that an engineering role is consonant with their interest in a positive way. This leads to making career choices that are more congruent with ones interests and strengths and more job satisfaction.

The PREFER framework provided the foundation for the development of two tests. The PREFER Explore is a personal preference test that aims to inform students about the three professional roles and their preference for one or more roles based on their attitudes towards performing particular tasks (Carthy et al. 2019). The PREFER Match test is a situational judgement test that aims to trigger reflection on students' motivations, strengths and weaknesses by measuring to what extent engineering students are able to judge professional situations (Carthy et al. 2022).

The validation process of the tests involved a sample that was representative for the student population. For example, the PREFER Explore was validated in Belgium and Ireland with 260 engineering students of which 221 were male and 39 were female (15%). However, the validation process was about reliability analysis of the items to identify the preference for a professional role and about clarity of language and instructions. It was not investigated to what extent different groups of students, for example students with other cultural backgrounds who may identify differently with engineering, may experience, or perceive the test in another way than the majority of the current student population.

The PREFER tests were developed for engineering students to increase professional awareness, to trigger reflection on their future self and, as such, to better prepare them for the labour market. However, by broadening the view on engineering and breaking through the stereotypes, the PREFER Explore test has also potential in attracting and recruiting students in engineering education. The test is about discovering future professional roles and related interests and motivation, a helpful instrument in making a study choice. However, this was not yet investigated.

3 RESEARCH QUESTIONS

This study aimed to evaluate the PREFER Explore test for inclusivity. The study was conducted in Belgium, where there is a underrepresentation of female students and students with a migration background in engineering education (Craps et al. 2022). In this study, the following research questions were investigated:

- Do first year bachelor female students have a significant different perception on the PREFER Explore test than male students?
- Do first year bachelor students with a migration background have a significant different perception on the PREFER Explore test than students without a migration background?

In order to use the PREFER Explore test as a recruitment tool in secondary education, the research questions were also investigated with a group of final year secondary school pupils.

4 METHODOLOGY

4.1 Participants

A first survey was distributed in October 2022 among first year engineering students in KU Leuven, Belgium (N=802) during one of their classes. A second online survey was conducted in March 2023 with final year pupils in science or math tracks across 10 secondary education schools (N=172). The pupils completed the survey in class or during a free moment. Participants were informed that participation was voluntary, and that data was analysed anonymously. Ethical approval was obtained from KU Leuven Ethics and Privacy Committee (G-2022-5592-R3).

Table 1 shows the distribution of the sample over sex and migration background. For higher education, the demographical data was provided by the university's database. For secondary education, additional questions were included in the survey. Sex was measured by the sex on someone's passport or their self reported sex. In Belgium, it is possible to change the registered sex on the passport from the age of 16.

Following university guidelines, respondents are considered to have a migration background when they themselves, one of their parents or at least two grandparents, were not born with a Western-European nationality[2].

Table 1. Descriptive of the participants

	Final year secondary education	First year engineering students (higher education)
Males	81	600
Females	91	202
No migration background	154	726
Migration background	18	76
Total	**172**	**802**

4.2 Survey

Students filled in the ten item PREFER Explore test. Per item, three possible options were presented. These options must be ranked from most preferred to least preferred. The test was used for several years with engineering students in different years at the university and abroad. Based on user feedback, little adjustments were made to six items in order to be attractive for different groups and to increase understanding for pupils who are less familiar with engineering. For example, when talking about consultants, a brief definition of consultant was included. Some wordings were adjusted to increase more gender sensitive wordings (The European Institute for Gender Equality 2019; Stroi 2019). *Table 2* shows an example where a rewording appealed to more communal (female) wording. Due to the limitation of the length of this paper, a complete list of the items is available on request.

After completion of the PREFER Explore test, students received eight questions that evaluated how the participants could identify with the cases presented in the PREFER Explore test (see *Table 3*). Participants were requested to indicate their level of agreement on a four-point Likert scale.

[2] List of Western-European nationalities used by the university: British, Danish, German, Finnish, French, Irish, Icelandic, Liechtenstein, Luxembourg, Dutch, Norwegian, Austrian, Swedish, and Swiss nationality

Table 2. Example of a test item adapted for inclusive language.

Original item	Item adapted for inclusive language
You participate in an event that is aimed at stimulating knowledge sharing in your professional area. You can choose between different kinds of sessions. What sessions would you prefer the least and the most?	You participate in an event known in your field as the event to exchange knowledge and experiences with engineers and other partners. You can choose between different kinds of sessions. What sessions would you prefer the most and the least?

Table 3. Questionnaire to investigate perception of PREFER Explore test

The following statements refer to the cases where you indicated your preference. Please indicate your level of agreement (disagree, rather disagree, rather agree, agree)	
Q1	I think the cases described in the questions are interesting.
Q2	I think the cases that were described are realistic situations.
Q3	I enjoyed filling in the questions describing cases where engineers can end up.
Q4	I could empathise with the situations (future) engineers can find themselves in.
Q5	I found it difficult to select the most or least preferred option.
Q6	I could not link the cases to my perception of engineering.
Q7	The cases included words or terminology that I do not entirely understand.
Q8	Reading the cases have strengthened my interest in becoming an engineer.

4.3 Analysis

First, the role preference of students was calculated following the guidelines of Pinxten et al. (2020). A scoring key of +1 was used when an option was selected as most preferred, -1 when an option was selected as least preferred and 0 when the option was selected as neutral (middle answer in the ranking of the options). This resulted in a score per role that varies between -10 and +10. Second, data of the questions Q5, Q6 and Q7 (*Table 3*) were reversed because the questions were negatively phrased. They were analysed in R using the Wilcoxon test to identify significant differences.

5 RESULTS

5.1 Role preferences

Similar trends in role preference were found with first year engineering students in higher education (HE) and final year pupils secondary education (SE) with a mere preference for the innovative role and less preference for the customer-oriented role. As shown in *Fig. 1*, female students in both HE (M=-1.99, SD=4.00) and SE (M=-1.20, SD=3.60) had significantly more interest in the customer intimacy role than their male peers (HE: M=-2.94, SD=3.35, p<0.01; SE: M=-2.67, SD=4.09, p<0.05). In HE, a significant difference (p<0.01) was also observed for the operational excellence role focusing on process optimization with female students (M=0.54, SD=2.81) having less preference than male students (M=1.16, SD=2.79). However, the significant differences in preferences were found with small effect sizes (r between 0.9 and 0.18).

Fig. 2 shows the results for students by background. In HE, first, a small significant difference was found for the innovative role: students with a migration background (M=0.91, SD=3.36) have less interest than their peers with no migration background (M=1.77, SD=3.03) (r=0.08, p<0.05). Second, these students (M=-1.66, SD=3.78) have slightly more interest in a customer intimacy role than the students with no migration background (M=-2.81, SD=3.50) (r=0.09, p<0.01).

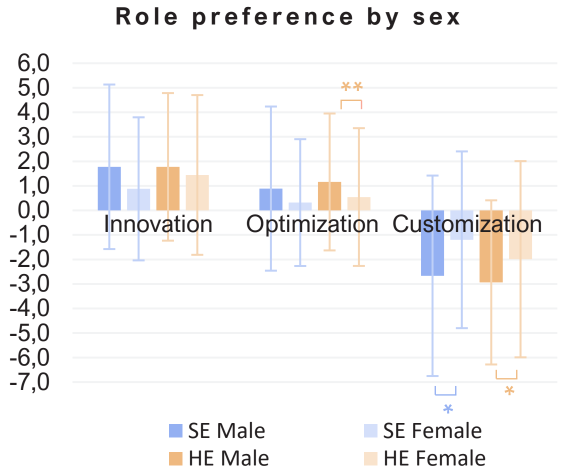

Fig. 1. Role preference of engineering students at university (HE) and final year pupils secondary education (SE) by sex (*p<0.05; **p<0.01; ***p<0.001)

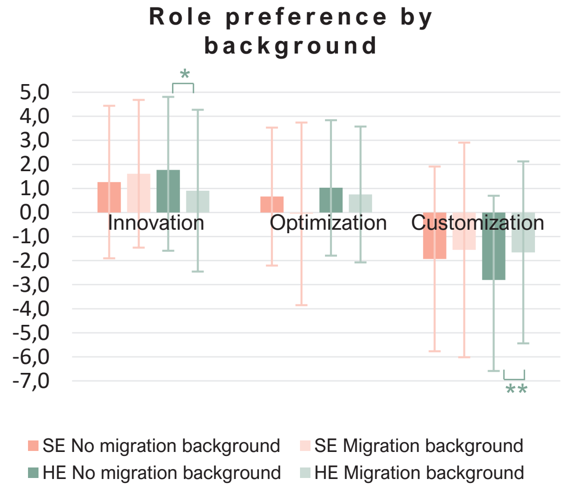

Fig. 2. Role preference of engineering students at university (HE) and final year pupils secondary education (SE) by background (*p<0.05; **p<0.01; ***p<0.001)

5.2 Differences in first year engineering students

The questions about how students perceived the PREFER Explore test scored above average for the different groups (*Fig. 3*). No differences were found in regard to how the different students groups liked the test, found the cases interesting or realistically described.

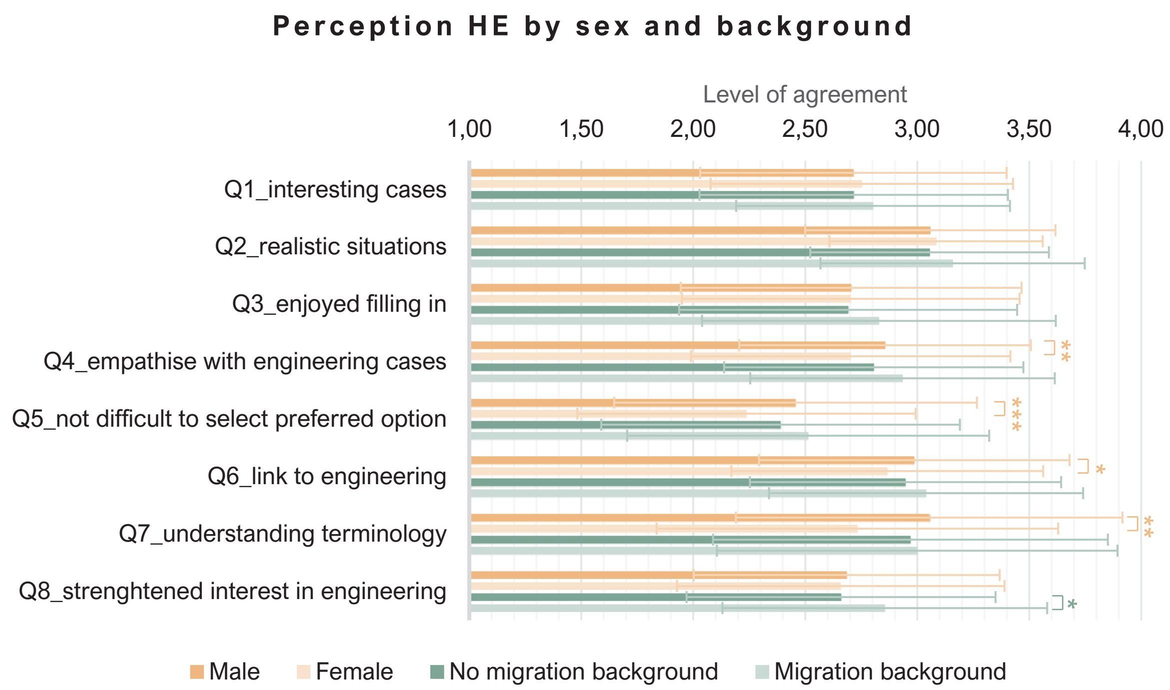

*Fig. 3. Perception of the PREFER Explore test of first year engineering students (HE) by sex and background (*p<0.05; **p<0.01; ***p<0.001)*

However, female students (M=2.7, SD=0.71) could empathise significantly less with the cases than the male students (M=2.86, SD=0.65) (p<0.01). Also, they could link the cases less to their perception of engineering (M=2.87, SD=0.70) than male students (M=2.99, SD=0.69) (p<0.05), had more difficulties in understanding the words and terminology in the items (M=2.73, SD=0.90) than male students (M=3.05, SD=0.86) (p<0.001) and in selecting their preferred option (M=2.24, SD=0.76) compared to male students (M=2.46, SD=0.81) (p<0.05). However, the significant differences were small (effect size r between 0.08 and 0.16).

Regarding background, a small difference was observed for students in regard to the impact of the test on interest (r=0.08, p<0.05). Students with a migration background indicated that filling in the cases had strengthened their interest in becoming an engineer (M=2.86, SD=0.72) more compared to students with no migration background (M=2.66, SD=0.69).

5.3 Differences in final year secondary education pupils

For secondary education, no significant differences were found between students with or without migration background (*Fig. 4*).

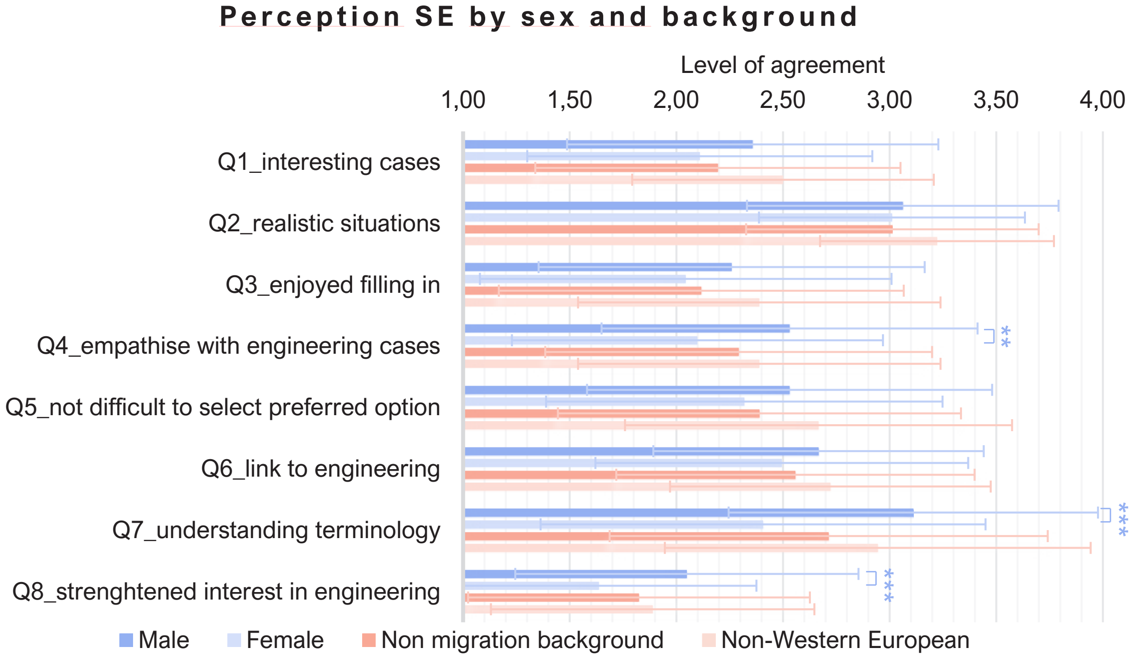

*Fig. 4. Perception of the PREFER Explore test of final year pupils secondary education (SE) by sex and background (*p<0.05; **p<0.01; ***p<0.001)*

Similar to first year engineering students, the female pupils (M=2.10, SD=0.87) could significantly less empathise with the situations (future) engineers can find themselves in than their male peers (M=2.53, SD=0.88) (r=0.23, p<0.01). Also, they had more difficulties in understanding the wordings and terminology (M=2.41, SD=1.04) than male pupils (M=3.11, SD=0.87) (r=0.33, p<0.001). The PREFER Explore test helped male pupils (M=2.05, SD=0.80) more in strengthening their interest in engineering than it helped female pupils (M=1.64, SD=0.74) (r=0.26, p<0.001).

6 DISCUSSION

It is important to recognise different identities and perspectives in order to increase the feeling of belonging in engineering for different groups and enhance diversity in engineering. This study investigated whether the PREFER Explore test can be used as an inclusive tool for diverse student groups by examining differences in perception between male and female first year engineering students, and between students without and with a non-Western European background in Belgium. It also examined the differences with a group of final year secondary education pupils in science/math tracks that prepare for engineering programmes at university.

In line with earlier studies (Carthy et al. 2022; Craps 2022), the PREFER Explore test seems to be sensitive for gender. This study shows the test seems also sensitive for migration background. For example, like female students and pupils, students with a migration background had slightly more preference for a customer intimacy role. Earlier research with engineering students showed that students were least familiar with the customer oriented role (Craps et al. 2019). When pupils are not aware that this role is an engineering role required in the labour market, they will less easily identify with engineering. This can negatively impact their choice to study engineering or to retain in the engineering programme. The communal and social aspect of engineering, that is more likely valued by women (Cech 2015; Bairaktarova and Pilotte 2020), is reflected most easily in the customer intimacy role that requires essential professional competencies such as clear communication (with people having non technical background), capacity for empathy, etc. (Craps et al. 2021). Therefore, it is important to make more explicit for (future) engineering students that engineer can take on diverse roles and what those roles require (Naukkarinen and Bairoh 2021).

When analysing the perceptions of the PREFER test with first year engineering students, it was observed that female students had more difficulties with empathising with the cases, linking the cases to their perception of engineering and with the wording and terminology. A perhaps logical consequence is that they found it more difficult to select their preferred options. Follow up research is required to better understand these small but significant differences. A possible explanation can be that words that are linked to engineering are, in general, more male biased, and, consequently, the items are still too male biased (The European Institute for Gender Equality 2019). Another explanation for the lower scores can be that women tend to underestimate their ability beliefs and in their self-confidence, in particular in male dominated fields (Bordalo et al. 2016; Perez-Felkner, Nix, and Thomas 2017).

An interesting finding is that students with a migration background indicated that the test had helped to strengthen their interest in engineering. In Belgium, one of the hurdles for this underrepresented group are a lower retention rate in the engineering programme. This finding strengthens the authors' belief that the PREFER tools can be useful instruments to strengthen the motivation and retention of this group. A next step in this research project will be the development of interventions for first year engineering students to motivate all students, and students with a migration background in particular, by explicitly work on their future engineering identity and the feeling of belonging in engineering (Craps et al. 2022).

The findings with secondary education pupils show that the PREFER Explore test is not yet ready as a recruitment tool that helps a more diverse group of pupils to choose to study engineering. The test helped to strengthen the interest of male students more compared to females, but the overall score was rather low. It should be noted that in Belgium, there is an open admission and a free choice to study any programme in higher education. This means that, although the participants were following science/math tracks that prepare for engineering, they can also opt for a study in humanities. Linking these findings to their interest in STEM would give more accurate results. Also, it would be interesting to include an intersectional approach of gender and migration background. In this study, a better understanding of the perception of females with a migration background was not possible due to the low numbers in our sample.

7 SUMMARY

Increasing diversity in engineering has never been more important. This study investigated how different groups perceived the PREFER Explore test: a personal preference test aiming to broaden the view on engineering and exploring one's motivations in engineering. The test was found to be sensitive for gender and migration background. Small significant differences were observed for female students who related less with the test, found it more difficult to understand the wordings and terminology or to indicate their preferences. More research is required to understand these differences. With regard to migration background no differences in perception were found, except for students with a migration background who indicated more often that the test strengthened their interest in engineering. These results are promising when developing interventions to increase motivation and retention in engineering. The study showed that focusing on the perception of different (underrepresented) groups is needed in educational development and research if we strive to increase diversity in engineering. By validating our tools and interventions with samples that represent the current (mainly white and male) students groups, we may unwittingly exclude (underrepresented) students.

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Exploring women's teamwork experiences in engineering education: a phenomenological analysis

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ABSTRACT

Teamwork, project or problem based learning, and other collaborative learning strategies are often presented as approaches that benefit women and other minorities during their studies in Science and Engineering fields of education. This is based on the assumption that underrepresented groups will respond positively to the social integration and cooperation encouraged by these learning methods. However, research also shows that gendered stereotypical presuppositions about attributes and interests can influence the performance of team members and the tasks developed, potentially providing opportunities to sexism, racism, and other exclusionary social behaviours.

In this context, this paper describes a piece of an on-going research project that examines the experiences of women studying engineering and the extent to which

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collaborative learning methods have supported their education. The study utilizes phenomenology as the primary methodological framework for data collection and analysis. The paper provides a description of the methodology employed, drawing on a subset of data from 22 college students who were interviewed.

Insights gained from narratives on group work by women studying engineering at a university in Ireland offer valuable perspectives on their lived experiences, allowing for a reassessment of the effectiveness of certain collaborative learning practices. Furthermore, as phenomenological research has become increasingly popular in Engineering Education Research (EER), this paper contributes to the refinement of methodologies for EER scholarship.

1. INTRODUCTION

1.1 Problem statement

According to the most up-to-date global data in higher education, participation rates of women in tertiary education degrees were increasing between 2016 and 2019; however, the gender gap of students enrolling in and graduating from fields in information and communications technology (ICT), Engineering and Manufacturing have remained almost unchanged (OECD 2021; World Economic Forum 2022). Additionally, while in 2019 more than half of all tertiary education graduates were female, the proportion of women graduating in STEM subjects dropped to 41% (UNESCO 2022). This indicates that although more women have been pursuing higher education, they are still significantly underrepresented in STEM fields.

Progressing women in engineering has been promoted for at least three reasons: (1) as means to support gender equality and social justice (Clavero and Galligan 2021; Rosa and Clavero 2022); (2) to tackle the shortage of engineers by attracting new profiles into the workforce (Beede et al. 2011; Moloney and Ahern 2022); (3) to ensure better results in engineering solutions, by increasing diversity in race and gender (Hersh 2000; Tannenbaum et al. 2019). In any case, research findings keep indicating difficulties in achieving wide student diversity in engineering, and this has encouraged pedagogical changes within engineering education (Berge, Silfver, and Danielsson 2019).

1.2 Existing research and research gap

Teamwork, project- or problem-based learning (PBL) and other collaborative learning strategies have been some of the teaching approaches implemented to support students pursuing degrees in STEM, particularly students who are women or from underrepresented minority (URM) groups (Du and Kolmos 2009; Du et al. 2020; Kolmos and de Graaff 2014). Nonetheless, there is also research showing the roles assigned to each member of the team and their performance might be influenced by gendered stereotypical assumptions (Beddoes and Panther 2018; Hirshfield 2018; Meadows and Sekaquaptewa 2013). Groupwork can provide opportunities for discriminatory behaviour such as sexism and racism, influenced by prejudices about minorities. These behaviours can lead to unequal task allocation and acceptance, and lead to further exclusion of URM individuals who might struggle to fully participate in the teams (Fowler and Su 2018; Okudan Kremer 2003; Wolfe and Powell 2009).

Even though it is generally agreed that collaborative learning supports students in their academic pathways in engineering, there is a need to better understand how engineering students undertake collaboration in a project team (Du et al. 2020).

Moreover, the lived experiences of women in teamwork may differ from those of men. Therefore, further research is needed to reveal the challenges women face in groupwork; it would be helpful to identify best practices for creating supportive learning environments for women and others from URM groups. By researching this, we can contribute to increased persistence and enhanced graduation rates of women and URMs in undergraduate engineering programs, ultimately leading to a more diverse and inclusive engineering workforce.

1.3 Research questions and aim of the paper

The on-going research project is framed by the following research questions:

1. What challenges due to gender dynamics have the women in our sample group faced in teamwork throughout engineering courses at university?
2. What strategies have these women developed to deal with these challenges?

This paper focuses solely on the first question and uses phenomenology as main methodology. The aim of this article is not only to explore insights on experiences of women in teamwork during their engineering courses, but also to demonstrate the practical application of phenomenological methodology as a contribution to the growing body of Engineering Education Research (EER) scholarship that uses qualitative research methods.

2. COLLABORATIVE LEARNING IN ENGINEERING EDUCATION

2.1 Team based learning pedagogies

Research has identified that project- and problem-based learning (PBL) have benefits in engineering students such as: (1) promoting deep approaches of learning instead of superficial learning, (2) improving active learning, (3) developing self-directed learning capability, (4) increasing the consideration of interdisciplinary knowledge and skills, and (5) developing management, collaboration, and communication skills, among others (Du and Kolmos 2009). Furthermore, PBL has also been shown to increase self-confidence and sense of belonging (Kolmos and de Graaff 2014; Du et al. 2020). A literature review of research on engineering students' perceptions of generic competence development in PBL, conducted by Boelt et al., (2022), found positive effects of teamwork.

However, PBL, as any other learning theory, can be transformative when it is contextualized, in terms of ideology, culture, power and race-class-gender differences (Mezirow 2018). Learning theories on teamworking suggest that in order for people to find a reason to work together, they must perceive a sense of identity and a need of a common purpose (Bates 2019). From the point of view of social psychology and according to Fiske (1998), the core features people use to make social judgment are gender, age and ethnicity. Based on those dimensions, individuals tend to build a continuum of "categories" to establish a variety of groups of people, who they perceive they can relate to or not. Such definitions also might add social pressure, if a person worries about either fulfilling the stereotype, or overcoming it when it feels like a stigma (Fiske 2010).

2.2 Gender and teamwork

Du and Kolmos (2009) have documented that project work in teams and collaborative ways of learning in engineering education help female students feel highly motivated and perceive that the technical part is less difficult to handle through peer-to-peer learning compared to individual learning. However, for women students in engineering, teamwork often means being the only female in the group, a condition that demands adjusting to a masculine culture (Charity-Leeke 2012; Dryburgh 1999). Moreover, being a woman in engineering and also part of a minority group could lead to feelings of intimidation due to having multiple underrepresented statuses; this condition might affect one's performance in teamwork, because it can foster the perception of needing to work harder to prove oneself (Dancy et al. 2020).

While gender is an important lens through which to analyse power dynamics and social relations, it is crucial to avoid essentializing and homogenizing women's experiences. A narrow focus on gender oversimplifies the causes of inequality in STEM (Alegria and Branch 2015)

3.3 Conceptual framework

The theoretical framework of the research is based in Schutz's social phenomenology (Schutz 1972; 1967). From Schutz's perspective, the analysis of social action needs to consider the subjective meaning that the actor gives to their own actions, including the inner motive of action. The daily life experience is essential to doing so. However, the discernment of the meaningful systems requires not only the observation of the actor's present experiences, but also an exploration of their past and the internally pre-projected future (Tada 2019).

It is appropriate to mention these theoretical premises because the interpretative work carried out with the data collected rests upon them. Four concepts of Schutz's theory are key to this research: stock of knowledge, life-world, intentionality, and projecting:

- *Stock of knowledge* refers to the information that people know and share with each other that, on the one hand, is created through social interactions and, on the other hand, helps us make sense of (and navigate) the world around us (Schutz 1967, 13). This information is accessible to everyone and can be adapted as an individual faces new challenges or encounters differences that their existing knowledge does not address.
- The concept of *life-world* denotes the world of immediate experience common to all of us, not the private world of any individual (Vargas 2020). It is the daily reality presented to groups of individuals as a shared world (Heiskala 2011).
- The concept of *intentionality* suggests that meaning in a personal experience is constructed by reflecting on past events and through relations with others (Heiskala 2011; Tada 2019).
- Finally, the concept of *projecting* consists in the anticipation of the future outcome of an action, based upon the knowledge at a hand at the time of projecting, that motivates actor's action (Schutz 1967, 20; Tada 2019).

3. METHODOLOGY

3.1 Research design

The use of phenomenology as the starting point for the research serves two purposes for this project: the first is to understand the women students' experiences studying engineering degrees. The second is to draw attention to the evolution in students' experiences along the engineering program that redefine their meaningful systems and, with them, their identities, behaviours, and plans in engineering. The phenomenological interviews informing this paper included a longitudinal component that supports analysis of such evolution.

3.2 Sampling and data collection

The subset of interviews used for this piece of research is part of a larger project initiated in 2014 by the research team (S. Chance and Bowe 2015; S. M. Chance, Williams, and Direito 2021; S. Chance and Williams 2016). For this paper, 42 interviews were used; they were conducted with 22 female engineering students at Technological University Dublin (TUD) in Ireland. The longitudinal dataset comprises students from a variety of sociodemographic backgrounds, an aspect that enables a diverse sample for an intersectional analysis on women and URMs. In Table 1, general information about the participants is shown.

Regarding the recruitment process, all the participants for the first cohort of interviews were self-selected. The inclusion criteria to invite them were two, the student was: (1) a woman[2]; (2) had started the engineering undergraduate program in TUD in the autumn of 2014. The research team conducted follow-up conversations with some of the participants (i.e., the second and third interview indicated in Table 1).

Table 1. Participants in interviews

No	ID	Country of birth	Years in Ireland*	Year in Major*	Field of interest in engineering*	Second interview	Third interview
1	IR01.1	Ireland	Birth	First	Structural or mechanical		
2	IR02.1	Ireland	Birth	First	Structural or manufacturing and design	Yes	
3	IR03.1	Ireland	Birth	First	Mechanical engineering		
4	IR04.1	Ireland	Birth	First	Mechanical engineering		
5	IR05.1	Ireland	Birth	First	Mechanical engineering		
6	IR06.1	Ireland	Birth	First	Indecisive, maybe electrical		
7	IR07.1	Ireland	Birth	First	Environmental engineering	Yes	Yes
8	IR08.1	Ireland	Birth	First	Indecisive of staying in engineering		
9	IR09.1	Ireland	Birth	Second	Electrical and electronics		
10	ME01.1	Oman	2	Second	Manufacturing and design engineering	Yes	Yes
11	ME02.1	Oman	3	First	Architectural engineering/civil engineering	Yes	Yes
12	ME03.1	Oman	1	First	Computer and communication engineering	Yes	Yes
13	ME04.1	Oman	3	First	Civil engineering	Yes	
14	ME05.1	Kuwait		First	Mechanical engineering	Yes	Yes
15	ME06.1	Kuwait	5	First	Mechanical engineering	Yes	
17	ME07.1	Oman	3	First	Civil engineering	Yes	Yes
17	ME08.1	Kuwait	2	Second	No interest in engineering		
18	FO08.1	Malaysia	2	First	Computer engineering		
19	FO09.1	USA	5	Second	Computer engineering	Yes	
20	FO10.1	India	6	First	Mechanical Engineering	Yes	Yes
21	FO11.1	Philippines	12	First	Mechanical Engineering / aeronautical engineering	Yes	
22	FO12.1	Philippines	6	First	Mechanical Engineering	Yes	

* At the time of the first interview.

Interviews were conducted by the second author, Professor Shannon Chance, using a phenomenological approach. They took the form of an open conversation around students' first experiences in studying engineering, the pleasant situations and the

[2] Note that the first inclusion criterion was embedded with assumptions: all students in the cohort presenting as female and presumably designated female at birth were invited to attend interviews. The participant's gender identity or gender expression was never explicitly asked, therefore, insights from the students can only be analysed with a binary approach of gender.

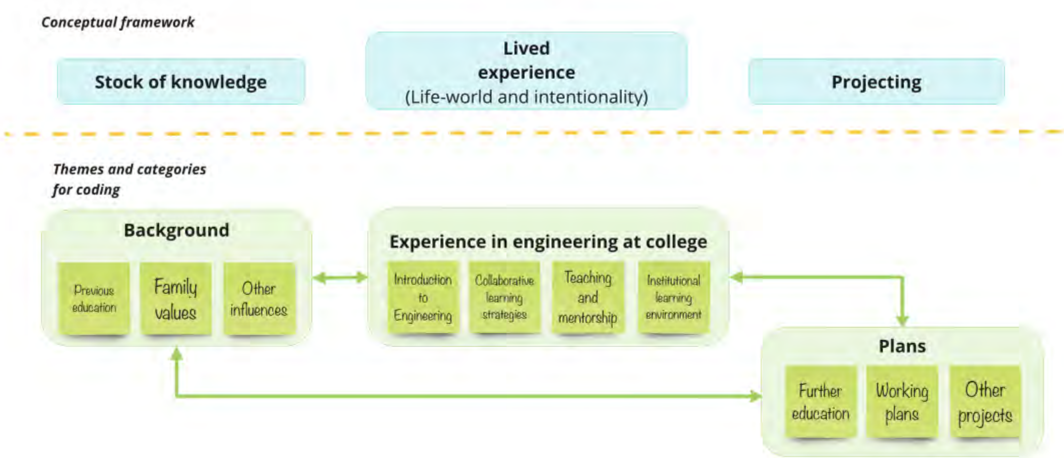
more challenging, thoughts on group-work, and feelings regarding the predominance of men in the classes. Students described and explained not only their experiences since they entered the university, but also shared stories about their families, friends, jobs and/or plans.

3.3 Data analysis methods

Following standard guidelines for Interpretative Phenomenological Analysis (IPA) (Alase 2017; Noon 2018), the initial step for data analysis was data immersion, which involved the lead author reading the transcripts while listening to the audio recordings of the interviews.

The second step in the data analysis was to code the data (Saldaña 2013). Three themes were determined beforehand by the lead author (deductive coding), based on the key concepts of the theoretical framework explained above. These were: (1) Background, (2) Experience in Engineering at college, and (3) Plans. Within each of these themes, an inductive coding was performed and meaning units were grouped as categories identifying patterns. Figure 1 shows the adaptation of the conceptual framework into coding themes and categories (due to space limitations here, not all categories are shown).

Figure 1. Coding themes and categories based on conceptual framework.



The interpretation of "meaning units" is an important step in the analysis process; it involves finding relationships between codes to create more profound and coherent units of analysis (Moustakas 1994). Given the scope of this paper, the focus of the analysis is centred only in the category of “collaborative learning strategies”.

After analysing and coding the transcripts two categories of “meaning units” of the students’ experience were distilled, regarding: (1) cultural practices in study groups, and (2) emotional aspects of teamwork. The first one comprises aspects of the group composition, the decision making processes, establishment of roles and norms, teaching practices and learning accomplishments. The second one includes the interpretation of enjoyable and frustrating experiences, cooperation and conflict, as well as feelings regarding sense of belonging and self-confidence.

4. DISCUSSION AND RESULTS

Phenomenological methodology aims to gain understanding not only on the participants’ experiences, but also on the meaning attributed to them. The coding system being used has allowed us to observe, on one hand, how students' life stories influence their experiences in engineering. This helps us make connections between their past and *stock of knowledge*, and their meaningful experiences in engineering courses. Additionally, understanding the students' projects and plans has helped us comprehend their decision-making processes (intentionality) and the subjective meaning they attribute to their daily experiences in engineering studies. This approach establishes a temporal context in which the phenomenon was experienced by the participants and enables us to track the evolution of its meaning.

Regarding the first research question (about the gender-based challenges that the sampled women have faced in teamwork), results are reported in the stages of a simplified PBL cycle: (a) Planning; (b) Execution; (c) Assessment.

4.1 Attitudes towards teamwork

Participants reported differing attitudes toward teamwork. Those who were content working in groups stated that learning is easier because people can help each other, share ideas, and draw on a variety of knowledge to develop the project. Furthermore, comparing results with those of other groups helped students to understand how problems can be solved from different perspectives.

In contrast, another subset of students reported finding teamwork challenging, mainly due to the following reasons: (1) not everyone being willing to cooperate; (2) having preference for more independent learning; (3) groups being too large to manage learning; and (4) lack of prior experience with group projects at the college level.

4.2 Planning the team project

Regarding their experiences in the planning phase, interviewees noted the advantages and disadvantages of selecting their team themselves or being assigned to groups by the lecturer. Choosing their own group facilitates students' interaction because they know (and trust) each other and recognize individual strengths. Often, when students are allowed to choose their teammates, they select those who are seated next to them because they are already friends or, at least, acquaintances from the course. Nevertheless, this familiarity can also result in inequitable workload, when students want to be accepted by their peers.

Regarding experiences with group designation, students felt frustrated when they were unable to choose their own group and ended up with teammates who were not as committed as they would have desired. Another challenging aspect of being assigned to groups is the diversity in the cultural background and language. Students noted that it was a positive experience to have people from different countries and regions, so they could learn a broader range of viewpoints. This was also beneficial in re-examining certain stereotypes. However, not speaking the same language as the majority in the group sometimes made students feel excluded. Narratives on this were mentioned not only by international students who struggled to communicate in English, but also by Irish students who were in teams where other members were speaking in their own mother tongue.

An additional topic in the planning stage of the project was the assignment of roles and the agreement on rules. Students' experiences demonstrate that being the project manager is a role more often assigned rather than chosen, as it carries more pressure and work. Three different female students described this experience:

- *They all kind of looked at me and it was like, “Yeah, you’re doing that”.*

- *And they all pointed at me. Didn't even say anything. They all pointed at me. And I was like "Fine".*
- *They just told me, "You be the Project Manager." So I just said, "Yes." I don't have the chance to say yes, but I don't mind because I'm okay at that.*

4.3 Execution of the project

The experiences related to the execution of the project describe the willingness of women students to assist other team members in completing tasks, particularly in the last-minute work. Students expressed frustration when attempting to motivate their teammates, as well as with the work itself, due to difficulty in finding solutions to emerging problems. For students with the role of project manager, having a set of rules was found helpful in establishing penalties for those who failed to show up or submit their assignments, without feeling like a whistle-blower or being too harsh.

Finally, some gender-related concerns around teamwork were disclosed by the interviewees: (1) assumption that they could be relegated away from decision-making on the project; (2) fear of shortage of technical knowledge; (3) expectations of solidarity between women; and (4) prenotions of women being more proactive than men at performing tasks for the teamwork.

4.4 Project assessment

The assessment stage comprises both learning accomplishments and the grades obtained at the end of the project. Overall, students recognized they were learning a lot from their peers and through having hands-on projects.

The perception of the relevance of the grades varied greatly among the participants. Some international students became very stressed out by the marks the team received and took on more work than had been agreed upon at the beginning to ensure the project was completed. In these cases, they were distressed at having the same grade as other members who did not work as much as they did.

Other students were satisfied with their project results, not because of the grades they received, but rather because of the effort they put in, the experience they gained, the mistakes they learnt from, and the fun they had building new friendships.

5. CONCLUSIONS

This paper aimed to reflect on challenges that women face in groupwork along engineering courses through phenomenological analysis. The women's lived experiences of engineering in team projects reflect attitudes and beliefs they have interiorized throughout their lives as part of their culture, family values and previous education experiences (stock of knowledge), which are the foundation in undertaking teamwork. The narrative of the interactions with team members shows not only aspects of the self-image and self-confidence of the sampled women students, but also the social dynamics they face with their teammates.

The significance of investigating gender-based interactions in close learning environments and the utilization of collaborative learning strategies is underscored by this analysis. By providing a detailed account of the research process, this paper can serve as a model for future phenomenological research in EER.

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EMPOWERING STUDENTS WITH GEOSPATIAL SOLUTIONS THROUGH CHALLENGE-BASED LEARNING

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ABSTRACT

Today, the field of Geospatial Solutions primarily focuses on spatial and mapping data, analysis, and technologies that primarily revolve around place and space. It is considered more as a tool or means rather than the ultimate objective of various interdisciplinary activities, where minimal attention is given to theoretical aspects, equations, and underlying principles of the subject. Conversely, despite advancements in science and technology and a broader audience for geospatial subjects, it is predominantly taught conventionally, disregarding the diverse needs and expectations of students. In recent years, there has been an exploration of innovative educational methods to utilize new pedagogical frameworks and enhance academic performance among students.

The present study aims to develop a framework and provide guidelines for the integration of Challenge Based Learning into Geomatics education. This framework consists of three interconnected phases: engage, investigate, and act. Subsequently, an educational pilot program is created and implemented to apply the designed

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framework to key topics such as food security and cultural heritage. Finally, the project refines the educational framework based on real pilot attempts and evaluation results, identifying potential issues and making necessary adjustments. The designed framework and the attained results are made publicly available for reference and utilization.

1 INTRODUCTION

The scientific and technological development witnessed in the last decades has radically changed the attitude to generating geospatial information, increasing the interest of scientists and practitioners from other domains like archaeologists, geologists, and ecologists. Related subjects are debated in a growing number of faculties, although in many cases, needs and expertise are different from pure geomatics courses. Geospatial information is seen as an “instrument” more than the final goal of their investigation: little, interest is given to theory, equations, and principles for the subjects.

Why CBL: Challenge-Based Learning aims at delivering education and knowledge by tackling and solving real-world challenges: teachers/mentors, stakeholders, and students are all involved in this process [1]. In the general CBL framework, stakeholders from the public, private, and non-profit sectors bring the real-world challenge, while students develop the technical solution thanks to the support of the mentors [2]. In this context, students acquire vital practical skills and discover how to apply academic knowledge in real-life scenarios that are usually not addressed in traditional education. This makes CBL especially appropriate for students from different disciplines seeking to learn about Geospatial solutions for tackling challenges in their respective domains.

Why Geospatial Solution: Geospatial solutions refer to all the data, knowledge, and technology used to acquire, handle, manipulate, process, and store geographical information. GIS, remote sensing, photogrammetry, and Global navigation systems are some related sub-topics here [3]. The added value of geospatial solutions is particularly evident in addressing Sustainable Development Goals and Global Challenges. However, The European geospatial analytics market is expected to develop at a rapid pace and is expected to grow at a Compound Annual Growth Rate (CAGR) of 14.92% over the forecasting period 2019-2027 (Europe Geospatial Analytics Market 2019-2027)[4].

Why CBL for Geospatial solution: Traditionally, Geospatial solutions are taught by providing detailed explanations of the underlying algorithms. While this approach is considered effective for training geomatics engineering, it may not align with the interests and expectations of students with limited experience in this field. In this context, CBL offers a valuable alternative by presenting education from a fresh perspective, integrating it with challenges that are more relevant to their studies. For instance, issues encountered in agriculture, geology, and cultural heritage can be redefined within this framework, making it easier for students to grasp and foster the development of innovative solutions through education.

The objective of this study is to provide guidelines for implementing Geospatial science education within a CBL framework. These guidelines are structured based on existing literature, discussions, and participation in workshops. Furthermore, the project refines the suggested educational methodology through a pilot course, allowing early identification of potential issues and offering a practical example to our community.

2 METHODOLOGY

The proposed methodology follows a general workflow consisting of five primary phases, as illustrated in Figure 1. The initial four phases are part of the framework development, where a versatile CBL-based educational framework is created. In the final phase, the framework is put into action, evaluated, and refined through a pilot implementation.

2.1 Engagement

In the engagement phase, the aim is to establish a connection between the students and the topic at hand. To achieve this, students are provided with the Big Idea and some initial guidance on transitioning from the Big Idea to Essential Questions. Throughout the Engage Phase, the focus shifts from a broad and conceptual Big Idea to a specific and actionable Challenge by employing the Essential Questioning process.

Essential questions, by nature, frame a topic as a problem to be resolved. They are open-ended inquiries that allow for multiple perspectives to provide answers. When formulating essential questions, it is crucial to take into account the viewpoints and requirements of stakeholders, as well as the predefined context [5].

In this phase, an elaborate document is created to facilitate students in understanding CBL (Challenge-Based Learning). Additionally, a comprehensive document is prepared for the Investigate phase, encompassing the concepts of Big Idea, Essential Questions, stakeholders, and challenges. Step-by-step instructions are provided to assist students in navigating through the CBL framework. Special attention is given to developing a detailed rubric to support students in the assessment process, which is both crucial and slightly intricate within the CBL framework.

- Phase input: The Big Idea, engagement phase guideline, assessment rubric
- Phase output: challenge proposal

2.2 Investigate

The investigate phase focuses on the collaborative efforts of all participants to address the challenge, leveraging their individual knowledge and skills, and considering what they are expected to gain from the experience. It involves planning activities that lay the foundation for actionable and sustainable solutions. The phase begins with guiding questions aimed at identifying the additional knowledge required to analyze and resolve the challenge. This phase acts as a bridge, transitioning from the challenge identified in the engage phase to the practical activities undertaken in the subsequent phase.

During this phase, the group members are tasked with addressing their defined challenge by seeking out relevant resources and activities that can assist them in gaining further information and knowledge directly related to the challenge. In practice, this phase encompasses three key components: Guiding questions, Guiding activities, and Guiding resources. These elements serve as a guide for the group members as they navigate through the investigative process.

For this phase guidelines and tables as well as rubrics are designed to help and support the students.

- Phase input: Challenge proposal, investigate step guideline, assessment rubric
- Phase output: Investigate phase report

2.3 Act

In the final phase, evidence-based solutions are formulated and put into action, drawing upon the findings derived from the Engage and Investigate phases. The act phase involves evaluating the results obtained and integrating the students' aspiration to make a meaningful impact or bring about innovation with their gained proficiency in understanding the big idea. This phase consists of three primary steps: solution concept, solution development, and implementation.

Solution concept: The investigation phase concludes with the establishment of a solid groundwork for the solution. In this particular step, the students will develop their plan to implement the solution. This step ultimately leads to the finalization of the solution concept.

Solution development: After the approval of the solution concept in the preceding step, the students will proceed with the development phase. Depending on the specific circumstances, they may be required to implement a code, conduct an experiment, administer a questionnaire, or create a prototype. Experiences encountered during this phase may prompt the students to revisit previous phases for revision, as necessary.

Implementation and evaluation: While the solution is developed, the students will continue with implementation. In this step, they need also to evaluate their solution, measure the outcomes, reflect on the results, discuss the findings, and report the failure or success process.

Throughout the Act phase, it is essential for students to maintain a continuous awareness of the previous phases. The results and findings obtained during this phase may give rise to new or modified guiding questions. As a result, the process becomes iterative, with this feedback loop serving to ensure that the solution remains efficient and has a meaningful impact on the challenge at hand.

Reflection, documentation, and sharing play crucial roles in CBL. It is important for students to document their experiences not only upon completing the implementation but also throughout the entire process. They should reflect not only on their own findings but also on the insights of others, if available. Once the implementation is finished and the results and findings are finalized, students are encouraged to share their work publicly.

- Phase input: Challenge proposal, Investigation document, assessment rubric
- Phase output: Implementation and findings sharing

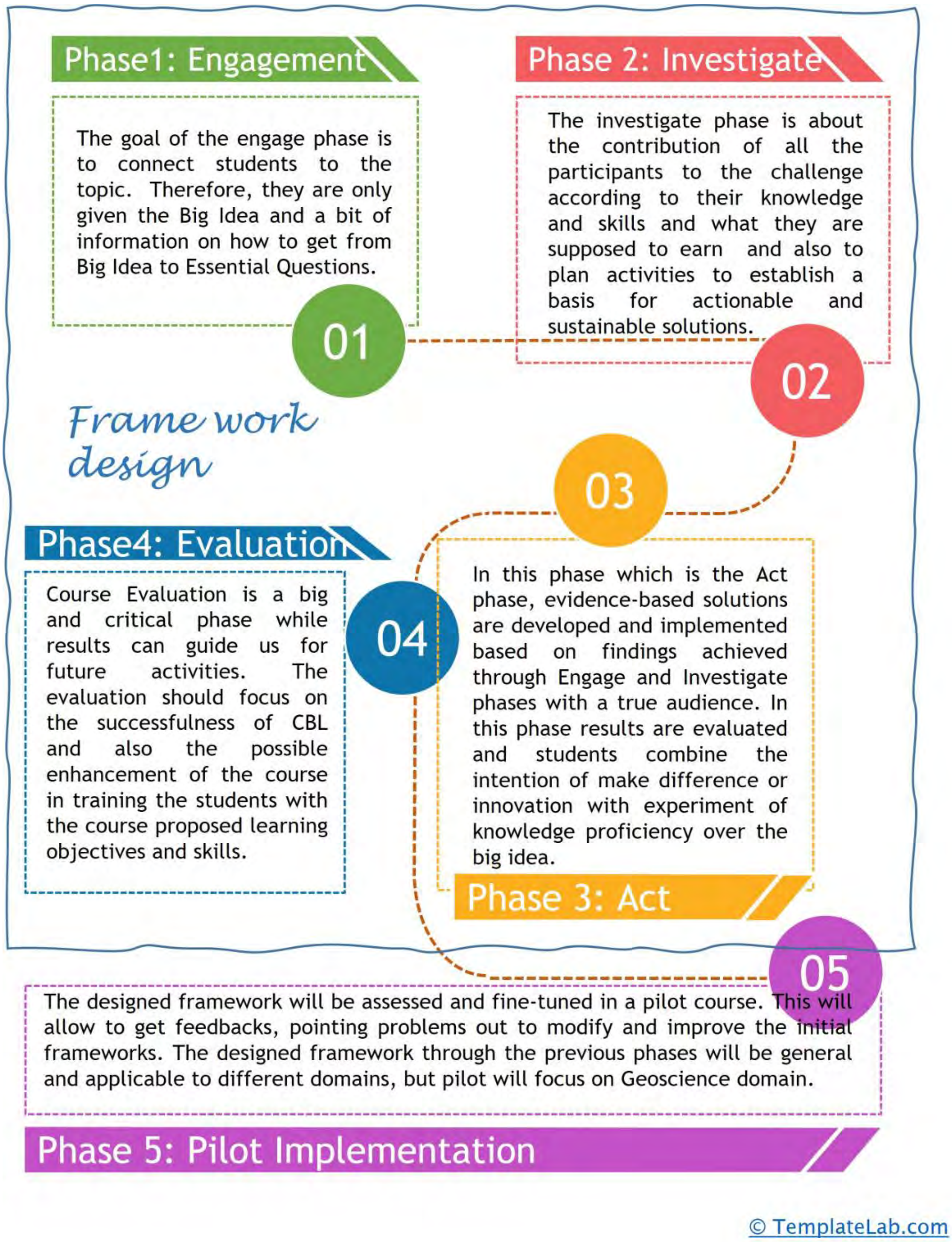

Fig. 1: Proposed CBL-framework strategy diagram.

2.4 Evaluation

The evaluation phase encompasses the assessment of not only the effectiveness of the newly designed CBL framework but also the accomplishments and contributions made throughout the project. As a result, the final evaluation strategy is developed during this phase, taking into account the following key elements:

- Evaluation of the new CBL framework using pre-designed questionnaires and via planning discussion sessions with all the people involved in the course.
- Evaluation of the whole course and comparing the results with those available from the previous years.
- For the evaluation, all the roles involved in the educational activities such as students, teachers, course coordinators, program coordinators, stakeholders, and supporting staff will be involved.

Dissemination, reflection, and feedback provision is the critical part of the project and will be handled in parallel with all the activities and modifications that will be considered respectively.

2.5 Pilot

To assess and evaluate the designed framework, pilot studies are required. In this particular phase, our focus is on UAV photogrammetry, an emerging technology with the ability to capture diverse geospatial data. Through the utilization of processing algorithms, the collected data can be analyzed, leading to the generation of valuable geospatial information. This information holds the potential to address various real-life multidisciplinary problems. However, many industrial and academic entities remain unaware of the potential benefits UAV photogrammetry offers in tackling their current challenges. Considering the flexibility, cost-effectiveness, wide availability, and capabilities of UAVs, they serve as practical and efficient platforms for data collection. Therefore, our study centers on UAV photogrammetry due to its significance. Furthermore, within the framework's scope, we also instruct a collaborative project focusing on the use of UAV photogrammetry for cultural heritage monitoring and documentation. This topic is selected as the Big Idea for our pilot study, considering its relevance to our educational program and the importance of food security.

3 RESULTS

The main purpose of this project is to design a framework based on CBL for teaching Geospatial concepts. For this purpose, five main phases are considered as discussed in the previous chapter. Here the experimental results are discussed.

For the first phase, the engagement document is designed. It has the intention of introducing the CBL concept to the students and motivating them on the advantages and added values of following such an educational framework. Then step by step guidelines are provided for them to follow. The main structure of the document is:

a) Introduction to challenge based Learning
b) Introduction to Big Idea
c) Introduction to Essential Question, Assignment 1: Essential Question

d) Introduction to Challenge Proposal, Assignment 2: challenge proposal
e) Assessment Rubric

The investigative document focuses on shaping the investigation activities of the students based on the main idea of CBL which is the importance of being involved with the real problem via actual stakeholders. The main structure of the designed document is composed of:

a) Introduction to guiding questions, factual and interpretative questions, Assignment 1: Guiding Questions
b) Introduction to guiding resources and activities, Assignment 2: Guiding resources and activities
c) Introduction to Analysis, Assignment 3: Analysis document
d) Introduction to Synthesis, Assignment 3: Synthesis document
e) Prepared forms for Guiding questions, activities, resources, analysis, and Synthesis
f) Assessment Rubric

For the Act phase, students are requested to carry out their projects. For this purpose, thy first are requested to conceptualize their proposed solution considering their investigation and engagement activities. Based on that, they will develop the solution and finally implement it in a way to address all the raised concerns and topics. The structure here is:

a) Introduction to Act phase; solution concept, solution development, solution implementation
b) Assignment: Act presentation

The evaluation phase is an integral part of this framework and is implemented during the pilot phase. The evaluation process primarily focuses on identifying the strengths and limitations of CBL, as well as encouraging students to reflect on their learning experiences through CBL. Specific questions are provided to assist students in comparing the CBL framework with their previous experiences in traditional knowledge-transferring educational settings. The evaluation phase aims to assess the added value of CBL and gather valuable insights from students' perspectives.

Moreover, evaluation is also needed to measure and weigh experimenting with CBL from an educator's point of view. Teachers, instructors, tutors, and stakeholders also experience different journeys of education where the feedback can help to improve the course and address the limitation. The main elements of this section are:

a) Evaluation form for the students
b) Evaluation form for the staff

The designed framework is implemented for educational purposes in two master courses, one at the University of Twente and the other at the University of Tehran. The primary objective is to apply the framework and make necessary modifications based on the lessons learned during the experimental phase. The mentoring team consists of a teacher, a local supervisor, and stakeholders. The teacher possesses experience in CBL, having participated in a pilot program while implementing her UTQ (University Teaching Qualification).

The pilot selected course A: For the implementation of the designed framework, a course that is embedded in MGEO master program in ITC faculty, University of Twente is selected. In this two-year Master's program taught in English, students will be equipped with the necessary skills to tackle a wide range of global challenges. These challenges include climate change, resource depletion, and pandemic diseases, which impact our society and vulnerable populations worldwide. Through the use of geo-information systems, students will learn how to effectively address these issues.

Throughout the program, students will gain theoretical knowledge, technical proficiency, and competencies in big data analytics. They will learn how to locate and access relevant data, analyze complex problems, visualize data, and develop innovative and sustainable solutions. With their newfound expertise, students will contribute to advancements in various domains such as food and water security, management of natural resources, geo-health, adaptation to climate change, urban development, and smart cities, disaster risk reduction, and responsible land administration.

The course is offered in the third quartile of the first year. During the first quartile, they learn the basics of Geo-Information Science and Earth Observation. The second quartile is dedicated to two courses from the specialization each has chosen.

It consists of two components; the first component introduces the students to a set of key global challenges which have been recognized internationally through keynote lectures and associated working groups. The second component of the course is a multidisciplinary and project-based investigation in interdisciplinary teams. With their project team, students will analyze a global issue more in-depth, and collaboratively design a response at the local level. The CBL pilot is implemented for the second component of the course.

A group of three students from the selected course is chosen for this pilot. These students are tried to be selected diversely based on their background and individual topic of interest. Moreover, for the group, a CBL-aware mentor, a local supervisor, and an external advisor are considered to support students during their projects.

The practice started with the initial introduction of CBL to the students. The CBL educational program is something new not only to the students but also to lots of teachers. Then the program is continued by asking the students in the same group to start talking and getting to know each other. The students are requested to talk more friendly about themselves and to get closer. This discussion will help them to know each other more closely and it can help them to decide about their future roles in the assignment. For these students, food security is considered their Big Idea.

The pilot selected course B: In the second pilot, jointly with the University of Tehran the designed CBL framework is tested for master students of Conservation of Cultural Property under the topic of UAV Photogrammetry for cultural monitoring.

Recognizing the demand for architects who possess expertise in both research and practice and acknowledging the aspirations of numerous architecture graduates to pursue further education in postgraduate and Ph.D. programs, the University of Tehran, the oldest university in Iran, initiated its part-time Master's program in 2002. This program admits approximately twenty students annually. In order to enhance the quality of architectural education, the program offers diverse design studios, each focusing on a specific theme. The Interior Architecture program was the first to be introduced in 2010, with an annual intake of around fifteen students.

The objective of this course is to let the students explore and practice the application of photogrammetry for cultural heritage studies. For this purpose, students are educated with basic concepts of photogrammetry and 3d modeling based on 2d images and computer vision-based processing methods. After learning enough about photogrammetric-based concepts, students are taught about UAVs as agile and flexible platforms for data acquisition that are playing an important critical role in today's Earth Observation science.

While the theoretical part is done, students together with their teaching team attended a real pilot on a UAV-based photogrammetry project and practiced the whole procedure from image acquisition to product generation. At this time when students are familiar with the concepts of UAV photogrammetry, they are requested to investigate and study its capabilities for their own discipline. For this purpose, the big idea is defined for them as UAV Photogrammetry for Cultural Heritage Monitoring.

Attendance composed of three master students all with backgrounds in architecture and cultural heritage documentation. The same strategy as course A is considered to prepare students with the concept of CBL and to guide them during the CBL trajectory. The whole developed framework including forms, guiding documents, presentation, and tables are presented openly and available to those who are interested via the project web page[4]. Moreover, sample results of conducted pilots as well as the evaluation and assessment results are also published. For sure the personal privacy concerns of the attendances are considered.

It is obvious from the achieved results that the CBL experience looks appealing mostly to the students and they found it a valuable educational methodology to be involved in. On the other hand, the teaching team is not so comfortable with this experience which might be due to two main concerns. Experiencing a new methodology is most challenging for the academic staff. Moreover, CBL enjoys a larger amount of freedom and flexibility rather than traditional education which is its advantage and at the same time can cause concerns for team leaders.

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[4] https://www.itc.nl/global-impact/itc-major-projects/!/cbl4uav

4 SUMMARY AND ACKNOWLEDGMENTS

This project aims at the framework development for conducting educational activities based on adopting Challenge-Based Learning and developing that for master course implementation in Geomatics Engineering. The framework is designed and it is openly published and accessible through the project web page. Some key findings from the executed pilots can be summarized:

- Students mostly found the CBL practice more time-consuming than their previous normal knowledge-transferring experiences
- Students believe more effort is needed to handle CBL and more team working involvement is desired
- They found CBL more promising in providing them with the practical knowledge and skills they are supposed to learn after attending the theoretical part of the course
- Students at these course pilots mostly prefer CBL to the normal education
- Students find CBL less successful in course content knowledge provision
- Staffs find the assessment part of the CBL the most challenging issue
- Staffs find their role at CBL more supervisory than normal education
- Staffs believe CBL is more successful than normal education for the practical part of the courses and they are not sure if it can be a good replacement for knowledge transferring in traditional education

Assessing students in CBL educational courses can be a challenging task, particularly when it comes to grading. On one hand, we need to evaluate students based on the established learning objectives of the course, which is similar to conventional assessment practices. However, on the other hand, the active involvement of students in the challenges presented in CBL requires additional assessment considerations. This is because participating in these challenges demands significant time, effort, and energy from the students. As a result, there is a need to place greater emphasis on developing assessment protocols for future studies in order to address these unique aspects of CBL.

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Innovating Pedagogy, Space and Technology in a South African Engineering Classroom

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ABSTRACT

The rapidly changing technological context of higher education has led researchers to reconsider the learning environment – both physical and digital. Current advances in information and communication technologies (ICTs) might enable new learning spaces and support a more effective pedagogy. Furthermore, the engineering curriculum should undergo change in order to be in line with industry requirements and, as a result, teaching and learning should also change. While ICT offers many opportunities, the challenge is to ensure that teaching and learning adapts to and utilizes new techniques and tools in pedagogically meaningful ways. The aim of this study is to discuss how academic learning spaces transform teaching practice, by investigating one lecturer's perceptions of a "future-fit" classroom and how such classrooms impact the lecturer's approaches to teaching and learning. "Future-fit" classrooms are technologically advanced and flexible learning spaces in which innovative and multimodal teaching approaches can be implemented. This research

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focuses on an engineering module in which a blended teaching and learning approach was used, combining ICT–mediated and web-based activities, the learning management system platform, face-to-face collaborative tasks and teacher-directed instruction. We observed classes in three formats (hybrid, online and face-to-face) and conducted two reflective interviews with the academic involved. The findings reveal three important themes: the design principles of learning spaces must be carefully considered; in order to create rich, engaging learning experiences pedagogical modes/practices must match learning spaces; and finally, technology can have a transformative impact on teaching and learning in higher education institutions (HEI).

1. INTRODUCTION

The use of technology has become ubiquitous in higher education; however, many university teachers, particularly in the global South, are not confident with using technology when teaching. As a result, engineering curricula often maintain the predominance of “chalk and talk” modes of pedagogy, which often leave students disengaged from what they are learning. Technology offers access to new modes of teaching and learning, but needs to be used in pedagogically meaningful ways. Lecturers are required to teach in innovative ways, using innovative technologies, but are required to do so in classrooms designed and built many decades ago. This is problematic because the spaces we operate in lock us into traditional ways of teaching and learning. There is growing recognition that the classroom environment is a central ingredient in determining pedagogical choices and student engagement, as “spaces are themselves agents for change” (Oblinger 2006, 12). Engineering students need to be prepared for a complex world and engineering teachers need to be better capacitated to educate engineers for a sustainable future by adapting their pedagogy towards more innovative teaching methods.

This study focuses on academic learning spaces. Drawing on observations, interactive interviews and researcher reflections, the study sought to explore how innovative academic learning spaces (ALSs) transform teaching practices in an engineering classroom. An understanding of how lecturers utilise space and teach within the spaces they inhabit will enable the higher education (HE) sector to actively harness and enhance those spaces for independent and co-learning opportunities and design better learning spaces – and pedagogies – in the future.

2. LITERATURE REVIEW

Cox and Marshall (2007, 59) list five reasons for knowing more about the impact of information and communication technologies (ICTs) on pedagogical practice and student learning, namely: (a) informing government policies; (b) directing teacher education programmes; (c) advancing national curricula; (d) designing or reforming classroom implementation and (e) analysing costs and benefits. These functions cannot be addressed if engineering educators are not capacitated to focus on new ways of teaching and learning. In an age where information is readily available everywhere and the role of the educator is undergoing great change, it is important for educators to remain key actors in facilitating students’ transitions to sustainable ways of life. In order to guide and empower students, educators need to be empowered and equipped with the knowledge, skills, values and behaviours that are required for this transition. Educators need to ensure that the learning environment is a safe space and should enhance this space by reducing barriers to participation and permitting students to explore new ideas and complex issues. Various studies have observed that the learning environment influences human behavior and has both direct and indirect consequences on learning and teaching performances.

The study of the design of learning spaces is a cross-disciplinary field with roots in education, architecture, design, and human-computer interaction (Boddington and

Boys 2011). Ellis and Goodyear (2016) identify two main domains within the research literature on learning spaces in higher education: physical and virtual learning spaces. They explain how research in physical learning spaces mainly tends to come from architecture (concerned with built space), environmental psychology (concerned with space design issues) and the learning sciences (concerned with pedagogy and curriculum design issues). The desired learning outcome should inform the selection or configuration of the learning space (Ellis and Goodyear, referring to Brooks 2011, 18). Ellis and Goodyear (2016) highlight the relational nature of different aspects of the learning environment. They emphasise that "the design, management and use of learning space should be a shared concern for all members of a university: a collective responsibility, the discharge of which can benefit all participants” (Ellis and Goodyear 2016, 2).

Spaces should be specifically designed to meet teaching and learning needs and the flexibililty of learning spaces is a priority. They should also be able to adapt to changing student demands, new pedagogies and technological advances. The literature (Boys, 2011; Mulcahy, Cleveland and Aberton, 2015) shows that space and its occupation are interlocked and dynamically inform and influence each other. This shows that it is not a cause/effect relationship, but rather a constant and dynamic interplay where each part affects the other (Ellis and Goodyear, 2016). The relationship between space and practice has always been complex as they endlessly inform and influence each other, but altering space does not necessarily change practice (Boys, 2011). The structure of space alone is insufficient to achieve changes in participants’ interactions in that space (Landsdale, Parkin, Austin and Baguley 2011); rather, a shift in how we think about learning spaces and pedagogy is required, as a learning space is more than a physical building in which learning takes place. Space and practice are interdependent rather than just reflective of one another.

By improving knowledge of the relationship between space and practice, teachers take control of the space and deliberately change it to support pedagogical enhancement (Martin 2002). Cleveland (2016) and Martin (2002) also emphasise that the appropriation of space depends on the users and their environmental competence, so users must have the ability to actively use and re-design their physical environment to fit their pedagogical practices.

The PSTU (Pedagogy-Space-Technology-User) framework shows the links between space, teaching and learning (Radcliffe, Wilson, Powell and Tibbetts 2008; Manciaracina 2019), as depicted in Figure 1. Manciaracina (2022) explores the critical relationship between space, pedagogy, technology and the user, with a specific focus on the latter since it is the connecting element that relates to all contexts. Technology facilitates the use of space and enhances pedagogy. Space that embeds technology encourages certain pedagogies, while pedagogy is enabled by space and enlarged by technology. The user is positioned at the centre of the framework, which shows its significance and linkages to other elements in a complex innovative environment.

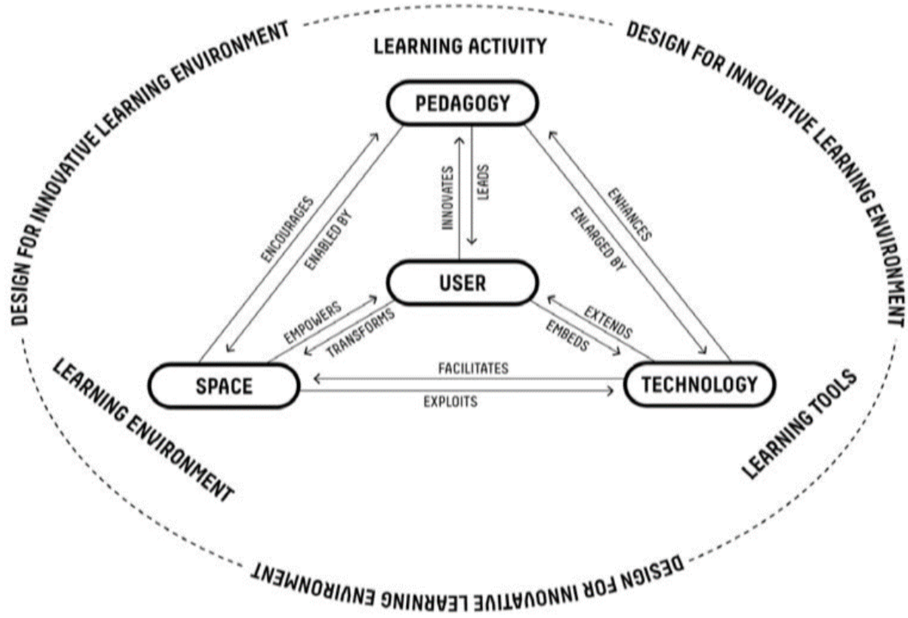

Figure 1: PSTU model based on Radcliffe et al.'s PST framework and updated by Manciaracina (2019)

3. RESEARCH DESIGN AND METHODOLOGY: PROJECT OVERVIEW AND EDUCATIONAL CONTEXT

The research presented here originated from a broader PhD study which focuses on how academic learning spaces can transform teaching practices. The broader research project involves five lecturers from varying disciplines in the university. A design-based research (DBR) study was carried out with a focus on collecting and analysing qualitative data. The teaching spaces used for this research included a technology-enhanced classroom, a traditional lecture hall and an online teaching space (see Table 1 that presents the spatial and technological features of these spaces). The technology-enhanced teaching space has collaborative tools, and is called a *future-fit* classroom. The teaching space blends Blackboard's *Collaborate* technology within the classroom, reducing transactional distance and providing students with the opportunity to use devices for collaboration. The lecture hall is a traditional teaching space, and Blackboard *Collaborate* was used for the online space. Data were collected in Semester 2 (June – November) of the 2022 academic year. This was an uncertain time post-pandemic as university campuses were cautiously opening doors to face-to-face teaching. While some classes remained online, others were face-to-face and others still were hybrid and blended. This 'liminal' state allowed for new realities as well as transitions in the teaching and learning space.

CLASSROOM ACTIVITY	SPACE	TECHNOLOGY USED BY THE STUDENTS AND INSTRUCTOR
Small group discussion	Future-fit Classroom • 20 single tables combined for group discussion • Portable group white boards • Wall mounted whiteboards • White desks that can be written on	• Ceiling mounted projector • Each group (4 groups) had one laptop per group • Glass writing walls • Wall-mounted display technologies for students
	Traditional lecture halls • Ordinary lecture hall • D-Shaped lecture hall	• Each student brings their own device (BYOD) to class • One projector screen at the front of the room • Instructor site is at the front left hand side
Class wide discussion	Future-fit classroom: • Instructor's station at the centre	• LCD monitors • Glass writing walls • Collaborate document cameras • Speakers • Control pads • Wirelss microphone and keyboards • Interactive pens

Table 1: Spatial and technological features of the academic learning spaces in our study

This paper reports on data collected from one lecturer, Dr O. The module she teaches is a first-year core module offered to electrical engineering students. The aim of the module is to develop students' professional and technical communication techniques, both oral and written. The module introduces students to basic engineering project investigation principles, such as conducting experiments, finding solutions and professionally reporting on results and conclusions. Qualitative data was collected in the form of interviews with Dr O, observation of her classes conducted in different formats (including recording of online, face-to-face and hybrid classes) and responses to open-ended questions sent to the lecturer via email. The lead author observed two lectures presented in the traditional lecture hall; the students then completed two assessment tasks which the lecturer marked. The lecturer suggested that before the major assessment task (a research report) for this course was due she would like to teach a class in the future-fit venue. She did a practice run in front of the lead author, a research assistant and some staff from the academic development unit of the university. The lead author then observed two hybrid classes taught in this venue. All these sessions were video recorded. The hybrid classes were 90 minutes each and the face-to-face class was 45 minutes.

The lead author then conducted reflective interviews after each hybrid class. Each interview lasted around 45 minutes. Permission was obtained from all the students to record the classes including their participation. We did not specifically interview students as the focus of this research was on the pedagogical strategies used in the different spaces.

The PSTU framework structured our analysis of the qualitative data collected. Each dataset was reviewed and organized based on the PSTU framework. Thereafter, codes were generated related to the four PSTU categories as well as the interaction between them. An internal reliability check was conducted by checking around 10% of the qualitative data, selected based on their significance to the findings. Themes and sub-themes were generated in order to generate a rich story and valid claims.

4. FINDINGS

Engineering educators must be prepared to work across different spaces to prepare students for sustainable futures. Three themes emerged from this study: the design of academic learning spaces must be aligned with teaching and learning developments; pedagogical practices must match academic learning spaces; and in order for technology to be relevant, it must be transformative.

4.1 Design of academic learning spaces and teaching and learning development

"Spaces are themselves agents of change. Changed spaces will change practice." (Oblinger 2006, 12). The design of learning spaces is an important resource that needs to be managed as an integral part of teaching and learning activities. Discussion with the lecturer showed how teaching in the future-fit classroom encouraged and promoted active learning. In Figure 2, the position of the teacher shows that she can actively engage with the learners in the classroom and promote active learning. The lecturer referred to how the design of the ALS is able to transform her teaching practices and encouraged her to adopt a more "*active teaching approach*", in order to "*actively engage*" her students in the learning process. In her view, the future-fit classroom gives a more *"engaging and immersive learning experience for students".* Yet, this approach does require practice and more support from the university's technical experts. In the first class held in the future-fit venue, there were many technical issues and in the interview the lecturer referred to how the university could better improve the classrooms to make teaching "*seamless in the future-fit classroom".*

She also referred to the help of her tutor: *"without the help of a tutor it's very hard to manage on your own. You have to have that support. Yeah. Otherwise it becomes very hard to manage it"*. The future-fit classroom also aided the tutor in assisting the lecturer, who highly valued the role of the tutors to "*equip them with using the technology when teaching".* When teaching in innovative spaces, a more engaging and immersive learning experience can be created for students, but this requires in-depth preparation on the teacher's part, which was not done for the first smart class, as this was the first time the instructor was teaching in the smart class while students were present. In the second smart class there was a significant change as the lecturer was better able to manage the learning space and the different technologies available. She was also better able to engage students both in the face-to-face environment as well as in the online space. The future-fit classroom aimed to introduce innovative technologies and pedagogies in the classroom. The lecturer mentioned this in her reflective interview:

> *as educators we need to accept the reality that if we think of technology and if we think of research, some companies and industries are … even far more ahead of the curve than research, and so academic researchers must follow*.

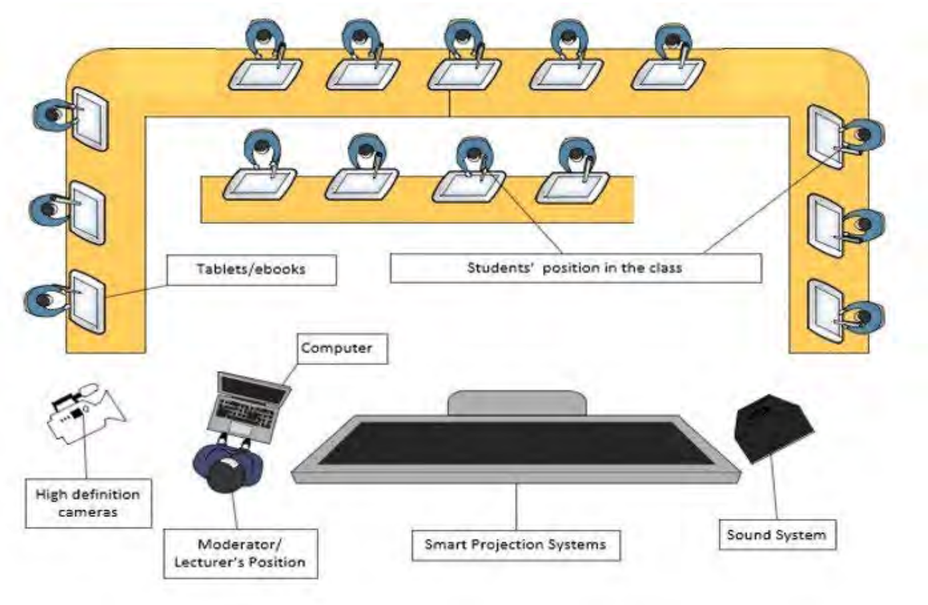

Fig 2: Layout of the experimental future-fit classroom

The lecturer also discussed how these spaces are able to support personalized learning as they provide students with a range of technologies that support different learning styles and preferences. Discussion with the lecturer showed how the design of the space can be better aligned with teaching and learning developments. The lecturer talked about how far ahead industry is and questions the validity of the type of education higher education institutions are providing:

> *the only thing going on for us, is how we [provide] the degree certificate, but the day another [cheaper, more viable] institution, such as, Coursera or another company offers the same, why won't our students go for the cheaper option.*

The lecturer argues here that there is a need to improve the space as well as the pedagogy, which leads to the second theme: that hybrid learning spaces (future-fit classrooms) need to be designed in a supportive, bold, creative and people-centred focus, as this can energise and inspire both lecturers and students.

4.2 Pedagogical practices must match learning space design

A conscious effort on the part of teachers is required to simultaneously engage students both online and face-to-face. According to the lecturer, one of the biggest problems faced by her (and, she feels, other lecturers) is the lack of engagement in the traditional classroom. The lecturer argued that she found the most engagement in fully online classes. In her reflective interview, she specifically mentioned that "*the switch between powerpoint and the whiteboard and show them how to solve the problem"* was easy for her and it was also useful because she was able to help students solve a problem, rather than teaching from a slide. Prior to collecting the data, the lecturer spoke about how important it was to create a rich learning experience for students and how teachers should focus on building and nurturing relationships. The lecturer argued that:

> *that is the whole part of exactly engaging students again, getting them to participate. You switch between the powerpoint and the whiteboard and use it [the whiteboard] to solve the problem. Yeah, it also tells the students the lecturer knows what they're talking about, not just showing me from a slide.*

The fact that the lecturer is concerned about the students being aware that she knows what she is talking about, is indicative of the fact that new technologies have helped to democratize knowledge, transforming when, where and how learning takes place. The key to aligning academic learning spaces to pedagogical practices is to create environments that allow for flexibility, that are adaptable and student-centred. In this way they can foster active, collaborative and authentic learning experiences. Therefore, understanding learning space design and creating efficient spaces can potentially improve pedagogical design.

4.3 Transformative technology

In future-fit learning spaces, students and teachers are better able to communicate with one another since they have more tools available at their disposal. Students may feel more comfortable asking questions and sharing their perspectives. As the lecturer mentions, "*in the future fit classroom, I feel they were participating more than those online*". The lecturer also praised the use of the future-fit venue as showing how technology can be a powerful tool for transforming learning. However, what was an important aspect for the lecturer was that sufficient training and practice was required: "*in the [future-fit classroom], I was able to access the whiteboard from my laptop and use it effectively. But I definitely needed practice*". In order to realize the full benefits of technology, educators need to use technology effectively in their practice. As she argued:

> *I used the technology to make an illustration. I can switch between the boards easily. I feel the practice we had during the pandemic helped, in fact …you need to prepare yourself mentally when teaching online.*

In order for technology to be transformative, educators need to have the knowledge and skills to take full advantage of technology-rich learning environments. The pandemic forced teachers to learn to teach with technology, but with little preparation. In order for technology to be transformative, a holistic approach that considers a wide range of factors, including pedagogy, technology and learning space design must be aligned.

5. CONCLUSION

"One of the most important aspects of technology in education is its ability to level the field of opportunity for students" (King 2017). The use of technology in education has always impacted both the content and delivery of lessons but, more recently, technologies like artificial intelligence are reshaping how we learn. Technology in higher education is a powerful tool for transforming learning. The term 'future-fit classroom' refers to an innovative approach to teaching and learning using technological tools that help students grow in their thinking, knowledge, and literacy. In other words, a future-fit classroom is a traditional classroom that has been upgraded to include advanced instructional technologies and educational resources. In this setting, students can engage in formal education in ways that go beyond what is achievable in a conventional classroom. So-called future-fit venues are becoming increasingly important academic learning spaces in universities and they play an important role in pedagogical innovation. Pedagogy needs to be interactive and learner-centred. In this type of pedagogy, the teacher acts as a facilitator, rather than a knowledge provider. The student needs to be active and responsible and spaces like the one discussed in this research allow for this.

Our aim in this article was to examine how academic learning spaces transform teaching practice and our data suggested that focused learning needs to take place amongst lecturers so that education itself can be sustainable, transformative and appropriate to our times. Dr O's case study provided insight into the importance of aligning learning space design and pedagogical practices, because learning spaces are constantly evolving and so pedagogical practices need to be studied and aligned to them. Envisioning this change and taking realizable, practical steps is the first step to transformative teaching practices.

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INCLUSIVE ENGINEERING CLASSROOMS: STUDENT TEACHING ASSISTANTS' PERSPECTIVES (RESEARCH)

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Keywords: *Inclusive teaching; student teaching assistants; diversity, equity, and inclusion; active learning, classroom climate*

ABSTRACT

Inclusive teaching is the intentional practice of recognising biases, working to mitigate their impact, and ensuring that students have equitable learning opportunities. In addition to improving students' sense of belonging and self-efficacy,

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inclusive teaching improves retention, improves academic performance, and reduces achievement gaps. In many large enrollment introductory classrooms, student teaching assistants (TAs) contribute to the classroom climate in addition to the teachers and the students.

In this qualitative study, 262 TAs were asked about their teaching strengths, areas that need improvement, obstacles, and ideas about their role in reducing incidents of discrimination or harassment. We coded their open-ended responses using a framework proposed by Dewsbury (2020) to map ideas about inclusive practices that these TAs are bringing into the classrooms.

Our analysis suggests that TAs can be powerful forces in building inclusive classrooms, given the coherency with Dewsbury’s inclusive teaching competencies. Following training, the importance they accorded to content knowledge decreased and active learning increased, coherent with increased focus on supporting students’ learning. Positive classroom climate dominated TAs’ ideas about decreasing discrimination in the classroom, however this did not feature among the teaching strengths they listed and many TAs cited a need to improve their skills in this area. However, empathising with students was also cited less often in the post survey, suggesting unintentional impact of the training that is counter to inclusive teaching. This suggests that TA training should be explicit about how inclusive teaching to fully exploit potential for TAs to foster inclusive classrooms.

1 INTRODUCTION

An inclusive classroom welcomes all students and ensures that everyone has access to an equitable learning environment and opportunities to succeed. Inclusive teaching is, therefore, the intentional and deliberate practice of making classrooms conducive for all students to learn. It involves, among other aspects, recognising personal and systemic biases, working to mitigate their impact, and ensuring that all students have equitable learning opportunities (Brame 2019).

1.1 Inclusive teaching leads to student gains

The detrimental effects of ‘exclusive’ teaching and ‘chilly’ classrooms in higher education and in engineering education are well documented. Inhospitable learning environments can lead to inequitable learning outcomes and opportunities (Aeby et al. 2019; Dececchi, Timperon, and Dececchi 1998), low sense of self-efficacy on disciplinary representative tasks (True-Funk et al. 2021), achievement gaps (Chang et al. 2011; Eddy, Brownell, and Wenderoth 2014), and student attrition (Geisinger and Raman 2013; Seymour and Hunter 2019).

On the contrary, inclusive teaching and inclusive classrooms benefit both students and teachers. They have been shown to improve student morale (Canning et al. 2019; Cooper et al. 2017), boost students' self-efficacy and intrinsic motivation (Freeman, Anderman, and Jensen 2007), and increase their sense of belonging - in the specific course, in the discipline and in science in general (Brown et al. 2015; Schinske et al. 2016; Zumbrunn et al. 2014).

The fundamental point is that inclusive education improves student learning outcomes. It improves academic performance and reduces achievement gaps

(Schinske et al. 2016), especially for minoritised students (Theobald et al. 2020) and those with lower prior academic achievement (Hardebolle et al. 2022).

1.2 Theoretical framework for inclusive teaching

In this paper, we use an inclusive teaching framework proposed by Dewsbury (2020) to explore the contributions of teaching assistants. The model consists of five competencies (Self-awareness, Empathy, Classroom climate, Pedagogy, and Network leverage) and the relationships between them. Dewsbury argues that inclusive classrooms originate with the teacher and their **self-awareness** of the philosophies that guide their actions and choices. This awareness can increase the teacher's **empathy** towards their students. Since the classroom is made of both teachers and students, a better understanding of both the parties then leads to inclusive **pedagogical choices** and a 'warm' **classroom climate**. Finally, by intentionally leveraging **support networks** and a wider diversity of resources, the students' learning experience in this one course becomes further integrated with their larger educational experience.

1.3 Undergraduate student teaching assistants contribute to classroom climate

Student teaching assistants (TAs) are employed to support student learning, especially large enrollment first year courses. These TAs are typically senior undergraduates who have previously taken the same classes who engage with the students in small group settings, resulting in significant one-on-one contact. While TAs' involvement in a course is usually not long term, they are highly-engaged with the students during the semester. Consequently, TAs could potentially contribute a great deal to the classroom climate and degree of inclusivity.

Previous studies have shown that TAs have a positive influence on students' academic performance. They have been shown to facilitate higher level cognitive thinking (Knight et al. 2015; Sellami et al. 2017), reduce achievement gaps (Van Dusen, White, and Roualdes 2016), and decrease failure rates (Alzen, Langdon, and Otero 2018), especially in minoritised students (Van Dusen and Nissen 2020). Additionally, having TAs correlates with higher student satisfaction (Talbot et al. 2015).

1.4 Research Questions

This paper looks at TAs' perspectives on their teaching and mentoring practices with an inclusive teaching lens. We specifically ask:

- What strengths, weaknesses and obstacles do TAs perceive for their capabilities to help students to learn? How does their perspective map onto the five elements of the inclusive learning framework?
- What are TAs' perceptions of their role in contributing to an inclusive classroom climate?

2 METHODOLOGY

2.1 Context and participants

At a premier European engineering university, the creation of a unit dedicated to improving learning outcomes for first year students increased the support provided to student teaching assistants (N = 250-300 per year) by the existing teaching support center. In 2021-2022, the two units collaborated and training for student TAs was revisited to reinforce the emphasis on giving feedback, teaching with questions and on guiding students to use an explicit problem-solving method. The training is facilitated by staff from these two units, and reinforced with trained doctoral assistants. The format of the training is an initial 3h workshop at the beginning of the semester, and two additional 1h sessions during the semester. The initial session includes a brief activity on the role of TAs around respect and discrimination in classrooms and in 2022-2023, additionally, the Equality Office of the institution began offering a webinar to all students about respect and discrimination on campus. With a view to evaluating the impact of the 5h of training, we collected impact data.

Our participants are current TAs, mostly second-year bachelor students who completed the course the previous year, working in teams of about three TAs per maths or physics classroom. Their role is to support first-year students to develop problem-solving skills and to organise their study time to succeed in a highly selective program. Most TAs reported none or limited previous teaching experience.

2.2 Data collection

Data for this paper was collected during the initial workshop of the 2022-2023 teaching assistant training cycle as part of a larger study investigating the impact in terms of TAs pedagogical activities. To assess changes in TAs' ideas about how to support student learning, we used ante and post surveys. In this article, we focus on TAs teaching intentions related to inclusion, as expressed in five open text items (a subset of all the data collected). The ante survey asked TAs about the skills they should improve. The post survey repeated this prompt, and also asked about their strengths, the obstacles they perceive to being a good TA, and their role in reducing harassment in the classroom. The data set was anonymous and did not ask for any demographic information.

3 DATA ANALYSIS & RESULTS

3.1 Data analysis

All 262 TAs attending the September 2022 sessions were issued paper surveys that used a unique identifier to link the ante and post versions. This enabled the data to be anonymised at the point of collection. Responses to the five open-ended prompts (n=223-245, 1 ante and 4 post) were coded with a mixed inductive-deductive approach coding scheme structured with Dewsbury's inclusive teaching framework (2020). Responses to the final prompt on TAs' role in reducing harassment was only coded inductively. Two coders, authors of this paper, coded the full set of data.

3.2 Mapping on to framework

The model proposed by Dewsbury has directional relationships between the five competencies, however our study explored only students' perceptions of the competencies and not interrelationships. Additionally, we split the competency 'pedagogical skills' into three sub-competencies to better reflect the themes from the training session: supporting students' belonging, engagement and active learning. Table 1 lists representative quotes from student responses that highlight their awareness and emphasis of these competencies.

Table 1: The 7 competencies for inclusive teaching with representative quotes from student teaching assistants

		Strengths, points to improve and obstacles to good teaching identified by TAs	Response to role in reducing harassment/discrimination
TA is **self-aware**		"I am confident" "I would like to be more friendly"	"Be kind and aware and woke"
TA is **empathetic**		"Be more patient"	"Listen, respect, without judging"
TA builds **classroom climate**		"Listening more to the students and optimising time spent with each student"	"Instal notions of respect and have zero tolerance towards those behaviours"
TA has pedagogical skills…	…to support students' **belonging**	"Helping someone who has a totally different approach and understanding their difficulties"	"Make students interact more in order to establish a good environment"
	to support students' **engagement**	"Motivating / giving positive feedback and making the student feel comfortable"	"Students should be able to give feedback to assistants"
	to support **active learning**	"Giving a lot of examples and ask a lot of questions"	-
TA leverages **networks**		"Discuss more with colleagues and prof"	"Be able to solve the problem with another TA, so that one can explain to the bully and the other reassure the victim"

Most ideas in the TA responses mapped onto the seven competencies described in Table 1. Ideas that did not directly map onto the framework but highlighted important aspects of the TAs' skill sets included self-efficacy and subject content knowledge, as shown in Table 2.

Table 2: TAs' ideas outside the inclusive teaching framework, with representative quotes

	Strengths, points to improve and obstacles to good teaching identified by TAs	Response to role in reducing harassment/discrimination
TA has **self-efficacy**	"I consider the subject as my passion"	"Be attentive to what is happening during the session and ready to intervene"
TA has **content knowledge**	"Good preparation and comprehension of the series"	-

3.3 TAs' responses describe a constellation of influences on their approach to teaching

Teaching assistants' responses contained a diversity of ideas relating to the competency elements for building inclusive classrooms (Fig. 1). These ideas do not appear with the same frequency, and differ in their prominence across the four general prompts given to the students. Ideas about pedagogical skills (including active learning and engagement) and empathy for the students featured prominently in their strengths, obstacles they faced, and aspects they need to improve in their roles as TAs (Fig 1 a-c). With respect to active learning and engagement, TAs' responses reflected themes from the training including using questions to guide cognitive tasks, modelling problem solving methods, facilitating group work, interacting with the students and being encouraging. The value of having empathy for the students was expressed through comments about listening to students, and being patient, kind and understanding. Although with lower frequency, TAs' responses also refer to other competencies including self-awareness (i.e. confidence, experience, asking for feedback) and supporting students belonging (being respectful, raising awareness of potential barriers to inclusivity).

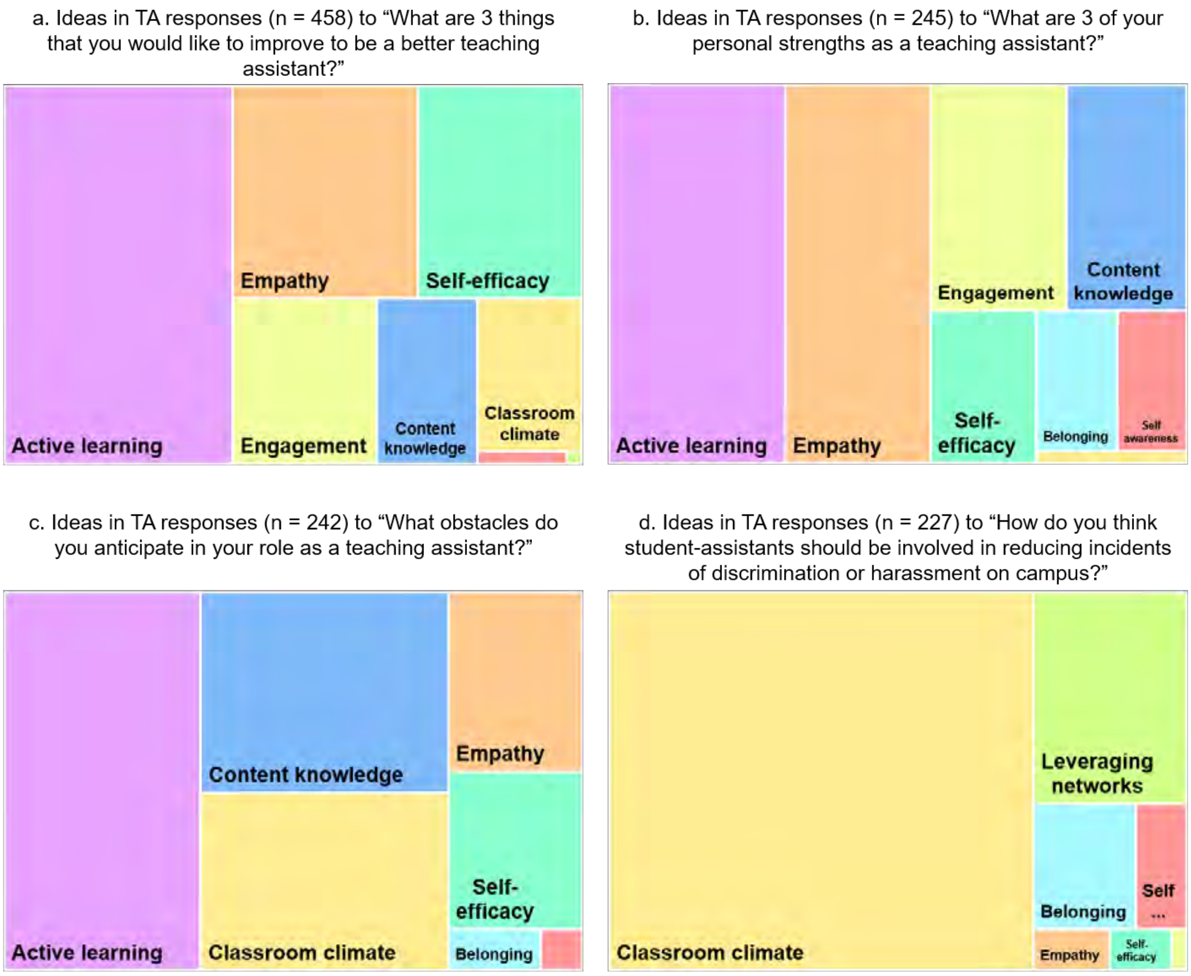

Figure 1. Relative frequency of ideas in TAs' responses grouped by the competencies in the inclusive teaching framework. See Tables 1 + 2 for colour legend.

In response to the final prompt about their role in reducing incidents of discrimination or harassment on campus, TAs spoke about actively working to build a supportive classroom climate, as well as leveraging the various support networks available to them and the students (Fig 1d). They highlighted being inclusive, setting an example, paying attention to classroom dynamics and taking action when needed as important aspects of their role as TAs when it comes to building the classroom climate. Interestingly, TAs brought up the importance of receiving training (including on harassment and discrimination), as well as being aware of the resources available to the students to promote inclusivity and deal with issues of discrimination.

A significant portion of ideas in TAs' responses did not directly map onto the competencies in the inclusive teaching framework. These can be grouped into ideas referring to self-efficacy (motivation, communication skills, time management) and to disciplinary content expertise (subject matter, preparedness for the day's session).

3.4 TAs' responses to aspects they need to improve change after the initial workshop

There is an interesting shift in the aspects that TAs listed that they need to improve to be a better teaching assistant at the beginning, and those they listed at the end of the initial training workshop (Fig. 2). Additionally, TAs' responses after the training were more likely to feature ideas relating to self-efficacy and classroom climate. On the other hand, ideas relating to empathy, engagement and content knowledge appeared with less frequency in the post survey as compared to the ante survey. The implications of these observations are discussed in the following section.

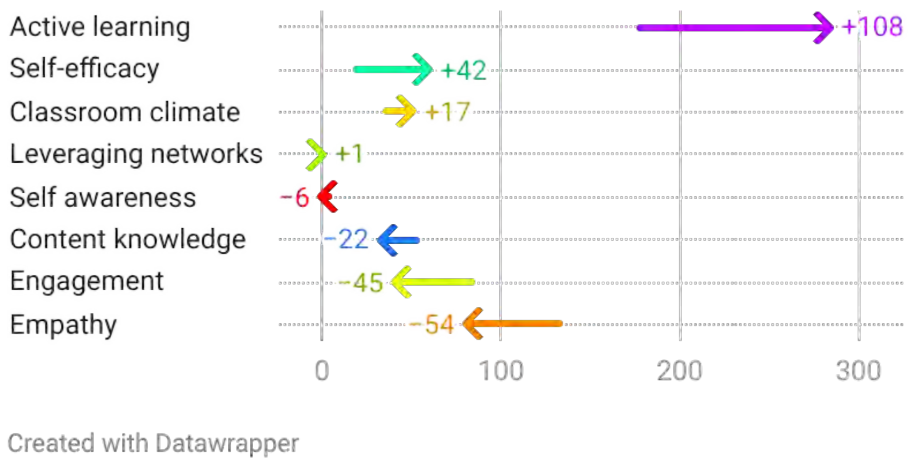

Figure 2: Changes in aspects cited by TAs to improve their teaching between ante and post survey, grouped by inclusive teaching competencies

4 CONCLUSIONS & IMPLICATIONS

Our data shows that TAs can be powerful forces in building inclusive classrooms. Without any directed intervention of training, they are already aware of, and prioritise multiple competencies of the inclusive classrooms framework. The TAs in our study identified developing their active learning skills as a priority for improving their teaching. Active learning has been shown to increase equity in learning outcomes (Theobald et al. 2020), including reducing achievement gaps, which in turn leads to increased retention especially of minoritised students (Harris et al. 2020).

The TAs also identified developing empathy for their students, and increasing their sense of belonging, as ways to become better TAs. These findings are in line with previous research that has shown that TAs can use their perspective as students themselves to propose strategies to reduce inequities in classrooms, and to make courses more inclusive (Wendell et al. 2019).

The changes seen in the ideas relating to aspects TAs stated they needed to improve before and after the workshop can be linked to the specific activities of the workshop. The workshop emphasised active learning strategies including teaching without telling (asking questions), giving process level feedback rather than task level feedback, and modelling problem solving strategies. The decrease in the prevalence of concern expressed by TAs to improve their content knowledge is coherent with this explanation. On the other hand, the decrease in ideas relating to empathy and engagement is potentially troubling. One explanation is that the training offered TAs enough support in these dimensions that were no longer priority areas to improve, or it could mean that TAs shifted their priorities away from empathising with students. Since empathy was not a focus of the training, this latter explanation may unfortunately be more plausible.

TAs' responses to the prompt on discrimination reflected many of Dewsbury's inclusive teaching competencies. Classroom climate dominated responses, self-awareness was cited infrequently, and while active learning figured prominently in TAs' answers to previous prompts, it was absent here. This suggests that TAs are not aware of the positive impact active learning has on inclusion. Empathy was also under-represented compared to their previous responses, suggesting TAs consider inclusion more at macro level class climate rather than impact on individuals. This prompt was the only time ideas about leveraging networks appeared.

Although TAs already possess ideas relating to inclusivity, training could help them hone their skills that they can then leverage to build inclusive classrooms. TAs in this study identified their need to further develop skills relating to active learning and empathising with students, both of which will also help with inclusion. Active learning, which was a major focus of the training the TAs received, grew in frequency in their responses while an unintended result was that empathy, which was not addressed in the training, was cited less often in the post survey than the ante survey. Building classroom climate featured often in skills to improve and obstacles but was rarely cited as a strength. This lines up with our previous research that showed that even after a practice-intensive 5 day course, doctoral TAs felt unprepared to foster good classroom climate as instructional choices were not made explicit (Isaac and de Lima 2022). Taken together, it is clear that TAs would benefit from more explicit training on inclusive teaching competencies.

In light of the important role that TAs play accompanying engineering students in their learning, explicitly developing TAs' inclusive teaching competencies is a promising way to make engineering classrooms more inclusive.

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CONCEPTUALIZING SOCIALLY SHARED REGULATION IN CHALLENGE-BASED LEARNING

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ABSTRACT

Students in Challenge-based learning (CBL) courses work in multidisciplinary groups to develop a solution to an open-ended and ill-defined challenge.Thus, in CBL, students need to regulate their learning individually and collectively to learn. Socially shared regulation of learning (SSRL) refers to the development of collective and co-constructed task perceptions or shared goals by multiple students working as a group. Existing knowledge about conceptualizing and researching SSRL in CBL is currently

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lacking. In this paper, we provide evidence from a qualitative study we conducted in a CBL course, using analysis of individual learning portfolios and in-depth interviews about students' perceptions of SRRL. We discuss, firstly, which individual characteristics students perceive as important for SSRL. Secondly, we discuss the identified processes of SSRL identified in our data. Finally, we discuss how groups with high and low SSRL differ. For example, groups with high SSRL spend more time in task planning and role division. They also discussed shared goals early in the process and frequently monitored and evaluated their collective work and progress.

On the other hand, groups with low SSRL need guidance individually and as a group to plan and evaluate their activities in different project stages. In addition, they had fewer conversations as a group about their shared goals, and they had more difficulties getting along at a social level. Finally, theoretical implications, practical recommendations, and future directions for research are discussed.

1 INTRODUCTION

Challenge-based learning embraces an active, student-centered approach that prepares students for the complexities of the real world (Gallagher and Savage 2020; Doulougeri et al., 2022a). By engaging in open-ended challenges, students are expected to learn independently and collaborate with their peers to develop their collective skills, such as teamwork and communication skills (Gallagher and Savage 2020, Doulougeri et al., 2022a).

When students work in collaborative groups, a relevant concept to consider is socially shared regulation of learning (SSRL), which refers to the collaborative effort where students support and regulate each other's learning processes (Hadwin and Oshige 2011; Panadero & Järvelä, 2015). SSRL encompasses the collaborative efforts of students within the same group, as they actively co-construct and adapt cognitive processes (e.g., developing conceptual understanding), meta-cognitive processes (e.g., fostering group efficacy), and emotional processes (e.g., developing trust for each other) through constant negotiation during the learning process (Hadwin et al., 2017).

SSRL plays a critical role in achieving success in learning, as suggested by previous research (e.g., DiDonato, 2013), and it can support students to take ownership of their learning, preparing them for success in both academic and professional contexts.

However, previous studies have already revealed that students might face difficulties regulating their learning at an individual level, and thus, regulation at a group level might present them with an additional level of complexity (Doulougeri et al., 2022b). In the CBL context, achieving SSRL can be challenging for students, especially encountering CBL for the first time.

Moreover, despite encouraging students in CBL to regulate their learning at a group level when tackling open-ended and real-life challenges, the individual regulatory processes employed by each student can influence the overall group regulation (Järvelä & Hadwin, 2013). Little attention has been given to the individual resources that each group member brings to the collaboration, such as prior knowledge, motivation, task-relevant information, and social skills. A review of SSRL by Panadero et al. (2015) emphasizes the importance of exploring the impact of individual self-regulation skills on SSRL to gain a deeper understanding of the concept.

To be able to foster and support students in successfully regulating their learning at an individual and group level, it is first important to study how students experience SSRL in CBL and what are unique resources each group member brings to the collaborative process. Current research does not explore how individual characteristics may either facilitate or disrupt the occurrence of SSRL. By addressing these issues, we aim to better understand how CBL can improve student learning outcomes and meet the needs of today's complex, dynamic educational landscape.

Thus, the present study investigates the relationship between individual characteristics and a group's SSRL within a CBL context.

2 METHODOLOGY

We conducted a qualitative, multimethod study within a CBL course for first-year engineering students focusing on ethics and data analytics. The course was conducted in the academic year 2021-22. The present study is part of a larger study, and its methodology has been reported elsewhere (Doulougeri et al., 2022a, 2022b)

The study employed two distinct methods of data collection:

a) Analysis of weekly learning portfolios, and b) conducting in-depth individual interviews.

The three groups selected for the study, each consisting of 4 students, were chosen purposefully based on their potential to represent important theoretical constructs relevant to the research.

2.1 Data collection

Weekly learning portfolia

Learning portfolia and reflections are useful tools for assessing socially shared regulation in higher education as they provide a space for students to gain a deeper understanding of their learning processes and how they can collaborate with others to regulate their learning. Moreover, learning portfolia and reflections can be used to highlight specific instances of socially shared regulation, such as developing learning strategies with peers or evaluating group performance. Examining these occurrences of shared regulation can provide valuable insights into how students work together to facilitate their own learning. For this study, we analyzed the learning portfolio of 12 students, which meant that we, in total, analyzed 120 weekly reflections.

In-depth interviews

In-depth interviews were conducted at the end of the course and offered valuable insights into individuals' experiences, strategies, social dynamics, contextual factors, and barriers and facilitators in students' learning (Doulougeri et al., 2022a). For this study, we analysed 10 interviews of students.

2.2 Data analysis

To analyze the collected data, the researchers utilized ATLAS.ti software, which allowed for the creation of an initial set of codes designed to capture the themes related to students characteristics that influence SSRL and SSRL processes.

After reading every student's learning portfolio and the transcript of the individual interview, we categorized the student as individuals exhibiting: low, average, or high self-regulated learning.

Then, the analysis happened at a group level, where we looked for a second time the portfolio of each student within a group and the interviews about their perceptions of their group and also categorized the three groups into low, average, and high SRRL.

Table 1 summarises the distinct categories which we identified for individuals and groups.

Table 1. The distinction of SRL and SSRL

	Low	Average	High
Self-regulated Learning (individual level)	Low SRL= difficulty to regulate own learning;	Average SRL= student needs some general guidance but shows proactivity and effort to regulate their own learning;	High SRL= students show evidence of regulating all cognitive, emotional, motivational, and meta-cognitive aspects of their learning in high level
Socially shared regulated learning (group level)	Low SSRL= difficulty in regulating learning as a group; need teacher guidance at the cognitive, meta-cognitive, and motivational levels	Average SSRL= Students need group support in some aspects of learning but show proactivity and effort to collaborate and regulate their own learning as a group;	High SSRL= students show evidence of regulating all cognitive, emotional, motivational, and meta-cognitive aspects of their learning at a high level as a group

2.3 Data synthesis

Through an auditing procedure, the final set of codes was collaboratively constructed by all members of the research team. The overarching goal of this research is to enhance our understanding of the processes involved in SSRL by investigating how individual group members' SRL influences shared regulation within collaborative groups.

3 RESULTS

3.1 Individual characteristics influencing SSRL

The results of this qualitative study, which involved synthesizing information from individual interviews, portfolios, shed light on the individual characteristics of group members that positively influence groups' SSRL. Four themes emerged from the analysis.

Theme 1: Intrinsic Motivation for CBL

The first theme that emerged from the data was the presence of intrinsic motivation for Case-Based Learning (CBL) among group members. Participants who showed a genuine interest and enthusiasm for CBL demonstrated higher engagement and active participation within their groups. Their motivation stemmed from an intrinsic desire to learn, solve problems, and explore real-world applications of ethics and data analytics. This intrinsic motivation drove their active involvement in group activities and discussions, fostering an environment conducive to SSRL.

Theme 2: Prior Experience with Active-Learning Pedagogies

The second emerging theme highlighted the significance of students' prior experience with active-learning pedagogies. Group members who had previous exposure to collaborative learning approaches, such as project-based learning, reported a greater familiarity and were more comfortable with the uncertainty open-ended projects like CBL entail. This prior experience enabled them to quickly adapt to the requirements of the group tasks and contribute meaningfully to the collaborative process.

Theme 3: Preference for Multidisciplinary Collaboration

The third theme surfaced was the preference for multidisciplinary collaboration among group members. Participants strongly inclined to work in diverse teams comprising individuals with different academic backgrounds and expertise demonstrated enhanced SSRL. These individuals recognized the value of multidisciplinary perspectives and actively sought opportunities to engage with peers from varied disciplines. The diverse knowledge and perspectives brought by different group members fostered more in-depth discussions, knowledge exchange, and problem-solving approaches, contributing to the group's overall success.

Theme 4: Social Skills

The fourth emerging theme emphasized the importance of social skills in influencing SSRL within groups. Group members who possessed strong social skills, including effective communication, active listening, and empathy, contributed positively to the group's SSRL. These individuals established and maintained constructive relationships with their peers, facilitating open and meaningful communication. Their social competence contributed to a supportive and collaborative group climate, encouraging active participation, knowledge sharing, and the development of a shared understanding.

3.2 Reported processes of socially shared regulation

The following aspects of group processes emerged from their reflections as relevant to how students experienced SSRL.

Theme 5: Shared understanding and goal setting

Students recognized the importance of establishing a shared understanding of project goals and objectives within their groups. They emphasized the significance of clarifying expectations, discussing individual perspectives, and reaching an agreement on goals and plans to ensure everyone was on the same page. A clear and shared understanding of the project facilitated effective collaboration and helped them work towards a common purpose.

Theme 6: Task division

Many students discussed the allocation of tasks within their groups. They acknowledged the necessity of dividing the project into smaller, manageable tasks and assigning responsibilities to individual members. By assigning tasks based on their strengths and expertise, students could maximize productivity and ensure the completion of all required components of the project. Effective task division helped maintain accountability and kept the group organized. On the other hand, other groups prioritized task division based on group members learning goals. For example, if a student already had programming experience, this task was allocated to another student so he/she could also develop the same skill. In the latter cases, students tended to work more in pair where a more and a less experienced group member collaborated for a certain task.

Theme 7: Time management

Time management was another group process that students highlighted in their portfolio reflections. They emphasized the importance of setting timelines, establishing deadlines, and monitoring progress to ensure timely completion of the project. Though important, very often, groups struggled with time management.

Theme 8: Monitoring and evaluation of working processes

Collaboration was a central theme in students' reflections. They highlighted the significance of open communication, active listening, and constructive feedback within their groups. Students recognized that collaboration fostered a positive and supportive group dynamic, enabling them to leverage the diverse perspectives, skills, and knowledge of their team members.

3.3 Differences in the three groups

For this study, we studied in depth three exemplary groups of students with distinguished differences in the way they experienced CBL individually and as a group. Important variations in SSRL among the three distinct groups- low, average, and high were revealed from the analysis of students' reflections.

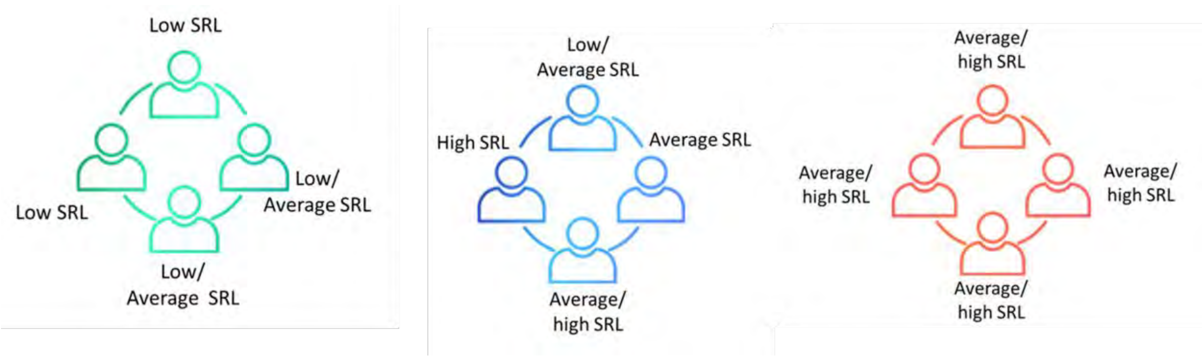

Figure 1. Composition of 3 groups with various combinations of SRL and SSRL

The low SSRL group faced difficulties in establishing a shared understanding of their task due to poor communication and social relations. They mainly worked individually and needed external guidance at every stage of the project, which led to frustration and dissatisfaction towards their team members. This affected their morale and productivity negatively.

On the other hand, the average SSRL group prioritized task division and time management, but spent less time in meetings and group discussions. The discussions were more focused on practical aspects than the content, hampering the overall learning process. They allocated tasks based on individual strengths and existing competencies, with a focus on optimizing the working process. Although they faced some frustration, the students proactively attempted to overcome problems and worked together.

Finally, the high SSRL group was dedicated to shared regulation of learning. They frequently brainstormed and set shared goals, monitored and planned as a group, and achieved a balance between individual and group work. They also conducted peer review sessions to reflect on group processes and emphasized learning together. This group exhibited a high level of collaboration and a positive attitude towards the challenge and each other.

4 SUMMARY AND ACKNOWLEDGMENTS

This study aimed to investigate how the self-regulated learning characteristics of students within a group affect their perception of socially shared regulation of learning. Our findings indicate that socially shared regulation of learning is a crucial component of collaborative learning in engineering education.

Successful groups do not only focus on working together but essentially learning together, spending time brainstorming and reviewing each other's work. Establishing a positive group climate that encourages mutual learning and support is important. This can be achieved by prompting students to discuss their strengths and weaknesses and learning orientation, reflecting on their learning, and coaching/scaffolding the learning and working process.

According to the study findings, it is essential to provide students with low SSRL the necessary support and guidance to help them become self-regulated learners and to help them establish effective group processes.

The findings of this study have implications for pedagogical approaches in CBL-courses. The results suggest that high SSRL groups are more effective at regulating their learning and achieving their project goals than low and average SSRL groups. The study stresses the importance for a group to establish a shared task understanding early on in the project and the value of focusing on learning together as a group rather than simply working together.

For further research, studying socially shared regulation using multiple methods is recommended. In addition, future research should explore the role of group composition on shared regulation in CBL courses. When a group involves diverse groups members, this may result in different perspectives and knowledge. However, at the same time, students' differences in learning and working processes can affect shared regulation.

In conclusion, this study highlights the importance of promoting socially shared regulation in collaborative learning settings, particularly in CBL courses, to facilitate students learning and positive experience with CBL.

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ASSESSING ENGINEERING STUDENTS' PREPAREDNESS FOR LIFELONG LEARNING AND SELF-REFLECTION COMPETENCY

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ABSTRACT

Lifelong learning is becoming increasingly important in the field of engineering. Higher education institutions (HEIs) are responsible for the transfer of field-specific knowledge, but also for preparing students for LLL. To do so, HEIs need a clear view of the extent to which engineering students are prepared for LLL. Research suggests two approaches in the assessment of LLL, namely (1) a holistic approach measuring general preparedness for LLL and (2) a specific approach measuring a subcompetency of LLL. The current study combines both approaches by using Kirby's lifelong learning scale (LLS) and Grant's Self-Reflection and Insight Scale (SRIS). Firstly, a correlation is found between the scales supporting the hypothesis that self-reflection is a subcompetency of LLL and the SRIS is useful for measuring preparedness for LLL. Secondly, the results indicate that early engineering students already have a relatively high level of self-reported LLL competencies, but with considerable room for growth resulting in a challenge for engineering education.

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1 INTRODUCTION

1.1 Lifelong learning in engineering (education)

As a rapidly evolving field, engineering requires constant adaptation and upskilling. With new technologies and developments emerging daily, knowledge that was once relevant can quickly become outdated (Chen, Lord, and McGaughey 2013; Van den Broeck et al. 2020). In addition to continuous developments in the field, the world is facing unprecedented global challenges such as climate change and social inequality, which requires engineers to master competencies beyond traditional engineering expertise (MacKenzie 2023; Dawe et al. 2022). Today, regularly updating one's competencies or lifelong learning (LLL) has become a requirement for engineers.

HEIs hold the responsibility of preparing students for their future career meaning that they also need to equip students with the necessary competencies for LLL (Yap and Tan 2022; Sankaran and Rath 2021; Van den Broeck et al. 2020). HEIs need to instil the importance of LLL in students and encourage them to take ownership of their learning process. By doing so, HEIs contribute to a workforce that is capable of meeting the challenges of an ever-changing professional environment.

1.2 Definition and measurement of lifelong learning

Defining LLL can be a complex task as seen in the many definitions in the literature. Fundamentally, LLL is the process of progressively acquiring, finetuning, and transferring of knowledge over long time spans while retaining previously learned experiences (Parisi et al. 2019). However, many authors go beyond this straightforward definition and accentuate the importance of the competencies that underpin LLL (Drewery et al. 2017) such as self-reflection, goal setting and self-monitoring. Self-reflection, for instance, is essential to set and reach learning goals and thus is necessary for lifelong learning (Love 2011; Mahajan et al. 2016). This way, LLL is defined using an underlying competency instead of a broad definition.

To prepare students for LLL, HEIs need a clear view on the extent to which engineering students are already equipped with the necessary competencies for LLL. Similar to the complexity of defining LLL, the measurement of LLL is equally challenging. Scientific literature has proposed a wide range of LLL questionnaires, such as the Evaluating Lifelong Learning Inventory (ELLI; Crick et al., 2010), the Jefferson Scale of Physician Lifelong Learning (JeffSPLL; Hojat et al., 2003) and the Lifelong learning scale (LLS; Kirby et al., 2010). These questionnaires result in a general indication of the preparedness for LLL, but start from a list of underlying competencies to create a comprehensive LLL measurement. The LLS (Kirby et al. 2010) for example, uses the characteristics defined by Knapper and Cropley (2000), namely goal setting, application of knowledge and skills, self-direction, and evaluation, locating information, and adaptable learning strategies to develop questionnaire items.

In a second approach, the extent to which students are prepared for LLL is measured using a questionnaire focusing on a subcompetency of LLL. Woezik et al. (2020) compared the effect of different didactic approaches on LLL preparedness using the Motivated Strategies for Learning Questionnaire (MSLQ). The authors argue that an increase in certain learning strategies from the MSLQ, like metacognitive self-regulation, indicate an increased preparedness for LLL.

Some research also compares a general LLL questionnaire with the measurement of an underlying LLL competency. In the context of engineering education, Chen et al. (2013) used the Autonomous Learner Scale to measure engineering students' study habits in combination with the LLS by Kirby et al. (2010). In conclusion, a large body of research measures LLL using an independently developed questionnaire focused on the measurement of a competency underlying LLL.

1.3 The current study

In this study, the preparedness of engineering students for LLL is assessed using two measures. The first measure is the Lifelong Learning Scale (LLS; Kirby et al., 2010), which provides a general measurement of LLL preparedness. The second measure is the Self-Reflection and Insight Scale (SRIS; Grant et al., 2002), which assesses the underlying competency self-reflection. This study aims to inform HEIs and engineering educators and researchers by answering the question ‘What is the state of engineering students’ preparedness for LLL?’

2 METHODOLOGY

2.1 Sample and procedure

Both measurements were conducted in-class during a lecture break in the first weeks of the second semester using a link to an online questionnaire. Data was gathered from the first (N = 40; N♀ = 5) and second year (N = 40; N♀ = 4) students enrolled in the Engineering Technology programme. Participation was voluntary and free of compensation. Ethical permission was granted by the Social and Societal Ethics Committee or SMEC (G-2022-5292-R2(MAR)).

2.2 Questionnaire

The first part of the survey consists of the Dutch translation of the SRIS assessed with a five-point Likert scale (1 = Completely disagree, 2 = Somewhat disagree, 3 = Neither agree nor disagree, 4 = Somewhat agree, 5 = Completely agree). The SRIS consists of 20 items and two factors. The first factor ‘Self-reflection’ is defined by 12 items measuring the engagement in and need for self-reflection and the second factor ‘Insight’ is defined by 8 items.

The second part of the survey was composed of the 14 items of the LLS-questionnaire with a five point Likert scale, all loading on 1 factor. Kirby et al. (2010) constructed the survey starting from five LLL characteristics (Knapper and Cropley 2000), namely goal setting (5 items), application of knowledge and skills (3 items), self-direction and evaluation (2 items), locating information (1 item) and adaptable learning strategies (3 items).

2.3 Analysis

The questionnaires are first analysed separately and then combined. All calculations, tests and visualisations are executed in RStudio (R Core Team 2022).

In the individual analyses, the mean, standard deviation, minimum score, maximum score and IIC (inter-item correlation) are calculated for all individual factors. Scores on reversed items are reversed before calculations so all included statistics are scaled in the same direction. A high score indicates a better preparedness for LLL and vice versa. All variables for each of the questionnaires are included in Table 1 and 2.

Internal consistency is quantified by both the mean IIC and Cronbach alpha. The IIC is the mean correlation an item has with all other items in a scale. An acceptable mean IIC value is situated in the range of .20 to .40 (Piedmont 2014). A higher IIC indicates that an item is highly correlated with other items and has little added value. A lower IIC means that an item is unrelated to the other items. In the case of multiple lower IIC values, these items probably measure a specific factor or construct. For the Cronbach alpha a value of .70 or more has been defined as an acceptable value (Yusoff, Arifin, and Hadie 2021) for questionnaire internal consistency.

The internal structure is assessed using confirmatory factor analysis on the two-factor structure of the SRIS and the one-factor structure of the LLS. Absolute fit is evaluated by the Root Mean Square Error of Approximation (RMSEA; <.08) and both the Tucker-Lewis Index (TLI; >.90) and Comparative Fit Index (CFI; >.90) are used to evaluate incremental fit (Yusoff, Arifin, and Hadie 2021). The two factors of the SRIS are also correlated with the level of significance set at .05.

Comparing both questionnaires is done using a correlational analysis with the level of significance set at .05. The SRIS factors and LLS factor are correlated and visualised using scatterplots.

3 RESULTS

3.1 Lifelong learning scale (LLS)

Descriptive statistics on item and questionnaire/factor level are included in Table 1. When inspecting the IICs in Table 1, it can be noted that the IIC values have a large range from -.20 to .33. The mean IIC ($\overline{\text{IIC}}$ = 0.14) is on the lower side according to the recommended range of .20 to .40. Subsequently, the standardized Cronbach alpha suggest a low but acceptable internal consistency (α = .70). Finally, to confirm the one-factor structure a confirmatory factor analysis was performed. Multiple goodness-of-fit indices indicate a reasonable fit (CFI = .80; TLI = .76; RMSEA = .07).

Table 1. Descriptive statistics of the LLS

	Mean	SD	Min	Max	IIC
LLS	3.44	0.43	2.57	4.57	
Goal setting	**3.41**	**0.55**	**2.20**	**4.8**	
I prefer to have others plan my learning (R)	3.40	1.10	1	5	-.01
I seldom think about my own learning and how to improve it (R)	3.51	1.00	2	5	-.18
I feel I am a self-directed learner	3.59	0.99	1	5	.22
I love learning for its own sake	3.24	1.08	1	5	.22
When I learn something new I try to focus on the details rather than on the ‘big picture’ (R)	3.30	3.30	1	5	-.12
Application of knowledge and skills	**3.77**	**0.63**	**2.33**	**5.00**	
I am able to impose meaning upon what others see as disorder	3.53	0.84	1	5	.26
I try to relate academic learning to practical issues	3.87	0.90	1	5	.33
When I approach new material, I try to relate it to what I already know	3.92	0.82	2	5	.31
Self-direction and evaluation	**3.42**	**0.68**	**1.5**	**5.00**	
I feel others are in a better position than I am to evaluate my success as a student (R)	3.39	1.10	1	5	-.20
It is my responsibility to make sense of what I learn at school	3.45	0.93	1	5	.31
Locating information	**3.12**	**0.88**	**1**	**5.00**	
I often find it difficult to locate information when I need it (R)	3.12	0.88	1	5	.18
Adaptable learning strategies	**3.27**	**0.69**	**1.33**	**5.00**	
I prefer problems for which there is only one solution (R)	3.26	1.09	1	5	.20
I can deal with the unexpected and solve problems as they arise	3.76	0.86	1	5	.28
I feel uncomfortable under conditions of uncertainty (R)	2.80	1.05	1	5	.06

3.2 Self-reflection and insight scale (SRIS)

Table 2 presents the descriptive statistics of the items and factors of the SRIS. The questionnaire shows a good internal consistency with a high Cronbach's alpha (α = .82) and a low mean ICC ($\overline{\text{IIC}}$ = .18). The IICs in Table 2 range from -.20 to .24 with mostly negative IICs for the Insight factor and positive IICs for the Self-reflection factor. This indicates the presence of two strongly distinct factors. The two-factor structure was largely confirmed with acceptable goodness-of-fit values (CFI = .80; TLI = .77; RMSEA = .10). As can be expected from the IIC pattern, the two factors are not correlated (r = .06, p = .62).

3.3 Relation between both measurements

The relation between the LLS and the SRIS is explored on factor level. The LLS factor correlates with both of the SRIS factors Self-reflection (r = .53, p < .001) and Insight (r = .34, p < .005). Figure 1 contains the scatterplots of both pairs of variables. The scatterplots includes one point for each individual at the x and y coordinates determined by the LLS mean score (x) and the Insight (left) or Self-reflection (right) mean score (y).

Table 2. Descriptive statistics of the SRIS

	Mean	SD	Min	Max	IIC
Self-reflection	**3.21**	**0.70**	**1.75**	**5**	
I frequently take time to reflect on my thoughts	2.92	1.18	1	5	0.18
I rarely spend time in self-reflection (R)	3.30	1.12	1	5	0.22
I often think about the way I feel about things	3.12	1.10	1	5	0.15
I don't often think about my thoughts (R)	3.57	1.16	1	5	0.24
I frequently examine my feelings	2.90	1.02	1	5	0.18
I don't really think about why I behave in the way that I do (R)	3.42	1.00	1	5	0.21
I have a definite need to understand the way my mind works	2.95	1.13	1	5	0.13
It is important to me to be able to understand how my thoughts arise	3.10	1.17	1	5	0.12
It is important to me to try to understand what my feelings mean	3.12	1.00	1	5	0.15
I am very interested in examining what I think about	3.12	1.10	1	5	0.16
I am not really interested in analysing my behaviour (R)	3.35	1.20	1	5	0.18
It is important for me to evaluate the things that I do	3.68	0.85	2	5	0.23
Insight	**3.49**	**0.62**	**1.88**	**5**	
Often I find it difficult to make sense of the way I feel about things (R)	2.34	0.95	1	5	-0.16
I am often confused about the way that I really feel about things (R)	3.48	1.00	1	5	-0.19
I'm often aware that I am having a feeling, but I often don't quite know what it is (R)	3.26	0.97	1	5	-0.14
My behaviour often puzzles me (R)	3.66	1.07	1	5	-0.20
Thinking about my thoughts makes me more confused (R)	3.27	1.13	1	5	-0.11
I usually have a very clear idea about why I have behaved in a certain way	3.62	0.90	1	5	-0.15
I usually know why I feel the way I do	3.47	1.07	1	5	-0.17
I am usually aware of my thoughts	3.75	0.78	2	5	0.08

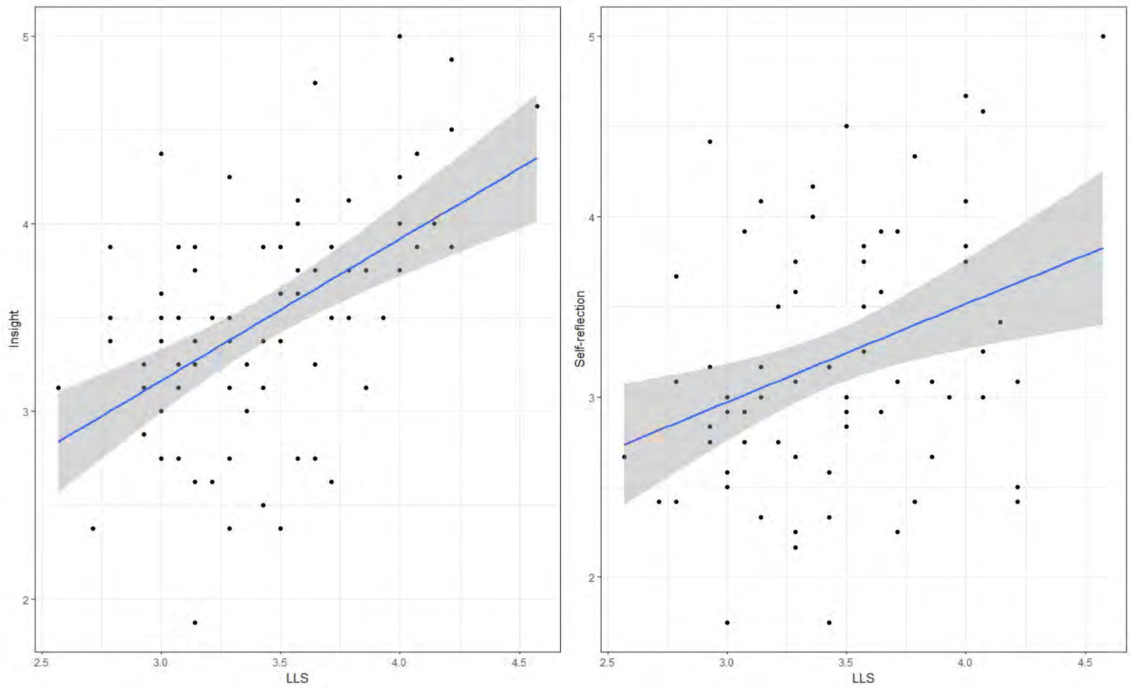

Figure 1: Scatterplot of LLS and SRIS subfactors

4 DISCUSSION

The current study assessed the preparedness of early engineering students for LLL using the LLS and the SRIS. The LLS is a comprehensive LLL questionnaire that takes a holistic approach on LLL, while the SRIS is a self-reflection questionnaire developed separately from the LLL research field. The latter was selected based on the hypothesis that self-reflection is a subcompetency of LLL since it is a central competency in achieving learning goals (Mahajan et al. 2016; Love 2011; Grant, Franklin, and Langford 2002). The measures were analysed independently and then combined.

4.1 Results of the LLS

Firstly, the analysis of the LLS data reveals that, on average, the engineering students rate themselves above the midpoint for each LLL characteristics included in the scale (M = 3.44). The mean overall LLS score is lower than in a study with engineering students from Malaysia (Yap & Tan, 2022; N = 109; M = 3.93; ∆M = 0.52). This difference in mean score could be caused by factors such as cultural setting, sample composition (especially gender balance), or the Covid-19 pandemic which was no longer a factor in the current study. However, more research is necessary to confirm this. In 2020, the LLS was also administered to students from the same programme at the same university (Van den Broeck et al.; N = 160) as the current study. In this study, a similar mean sum score was obtained (M = 3.37; ∆M = 0.04).

The highest mean score on a characteristic is on the 'Application of knowledge and skills' characteristic (M = 3.77). With items like 'I try to relate academic learning to practical issues', this is unsurprising considering the practical nature of the engineering technology programme. Additionally, for the item 'When I approach new material, I try to relate it to what I already know' not a single student indicated the lowest point of the scale, which is an encouraging result. The lowest mean score is for the 'Locating information' characteristic (M = 3.12). However, it needs to be noted that this characteristic exists of only one item, namely 'I often find it difficult to locate information when I need it'. Overall, the results of the LLS show that the engineering students are located above the midpoint of the scale, but with significant room for growth.

The Cronbach alpha value of the LLS in the current study ($\alpha = 0.70$) is considered low but acceptable, and is consistent with similar values reported in previous studies ranging from 0.52 to 0.73 (Kirby et al. 2010; Deveci 2022; Meerah et al. 2011; Yap and Tan 2022; Van den Broeck et al. 2020). Given the wide range of characteristics that the LLS attempts to capture, this level of internal consistency is expected.

4.2 Results of the SRIS

The analysis of the SRIS data shows that engineering students also estimate their Self-reflection (M = 3.21) and Insight (M = 3.49) competency to be above the midpoint of the scale. Previous research using the SRIS in the same programme as the current study (Tuyaerts et al. 2023) found similar results with a slightly higher mean for Self-reflection (divided into two subfactors) in the first bachelor ($M_{\text{Engagement in self-reflection}}$ = 3.32; $M_{\text{Need for self-reflection}}$ = 3.40) and second bachelor ($M_{\text{Engagement in self-reflection}}$ = 3.33; $M_{\text{Need for self-reflection}}$ = 3.33). For Insight, the mean was slightly lower in the first bachelor (M = 3.32) and second bachelor (M = 3.35) compared to the current study. Similarly to the LLS results, the SRIS results are positive but indicate room for growth.

Interestingly, a closer look at individual items reveals a response pattern. All items containing the words 'feel' or 'feelings' have mean response scores beneath the mean of the corresponding factor, for example 'I frequently examine my feelings' for the Self-reflection factor (M = 2.90; ΔM = 0.31) and 'Often I find it difficult to make sense of the way I feel about things' (M = 2.34; ΔM = 0.18). This is in contrast to items with behaviour or action as the focal point of reflection which are all higher than the mean score of the factor. Examples of this are 'It is important for me to evaluate the things that I do' (M = 3.68; ΔM = 0.47) and 'My behaviour often puzzles me' (reversed item; M = 3.66; ΔM = 0.17).

The absence of a correlation between the two factors self-reflection and insight ($r = .06$, $p = .62$) was also present in the original study by Grant et al. (2002; $r = -0.03$). In fact, this study even found a negative correlation ($r = -.31$, $p < .001$) when examining the congruent validity with a different sample. A large-scale data collection conducted by Silvia (2022) also found a weak correlation between the two factors ($r = 0.07$, $p = 0.04$) in line with the current study's findings. This indicates that the SRIS consists of two strongly distinct factors.

4.3 LLL and self-reflection

The LLS correlates with both the Self-reflection ($r = .53$; $p < .001$) and Insight factors of the SRIS ($r = .34$; $p < .005$). This is in line with the hypothesis that self-reflection is central to goal attainment (Grant, Franklin, and Langford 2002). In the context of LLL, self-reflection contributes to reflection on how one's progress towards a learning goal is going and how it can be improved. In this way, self-reflection is a necessary competency for LLL (Mahajan et al. 2016; Love 2011). The moderate to high correlation between the SRIS factors and the LLS further contribute to this hypothesis.

These results indicate that the SRIS could be used to provide insight into the preparedness for LLL. While a general LLL questionnaire may seem more useful at first glance due to its holistic and comprehensive approach, an opposing argument can also be made by looking at a different field of study. In personality research, it has been established that broad personality factors are useful for predicting general outcomes, while underlying personality facets are better for predicting specific outcomes. For example, the Big Five personality trait conscientiousness is the strongest personality predictor of academic performance. However, underlying facets of conscientiousness, such as perfectionism are more useful for predicting specific academic outcomes like absenteeism and high honours attainment (Maccann, Lee, and Roberts 2009). Thus, by focusing on smaller personality facets a more fine-grained analysis of the role of personality in academic performance is achieved. Similarly, in the context of LLL, a questionnaire that focuses on a subcompetency of LLL, such as the SRIS, may have advantages by providing a more detailed analysis of LLL and by extension informing HEIs about the strengths and weaknesses of students.

Following this argument, there is a need for a framework that maps the different LLL competencies (and their associated questionnaires) and how they relate to each other, in order to make better predictions of LLL. Currently, the literature is flooded with newly developed LLL models, character lists, and questionnaires, but with little reference to each other. By constantly reinventing the wheel, little progress in our understanding of LLL is actually made.

5 SUMMARY AND ACKNOWLEDGMENTS

The measurement of LLL is a challenging task but is necessary to adequately prepare engineering students for their professional life. The current study attempts to tackle this task by combining a general LLL questionnaire with a questionnaire focusing on the LLL subcompetency self-reflection. The results indicate that (1) early engineering students have already a relatively high level of self-reported LLL competencies, but with room for growth and (2) that both scales correlate.

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TEACHING EXCELLENCE PROGRAMMES – LESSONS LEARNED AT TWO UNIVERSITIES

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ABSTRACT

Universities are seeking novel ways to strengthen the collective educational competence of their faculty and promote educational merits. In this paper we describe and compare the experiences of two recently started initiatives for teaching excellence, the *Program for Future Leaders for Strategic Educational Development* at KTH Royal Institute of Technology (henceforth KTH) and the Teaching Fellowship

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Programme at the University of Twente. Both programs have recently completed one complete round of implementation. The programmes are similar in that the participants work on a project of their own for an extended time, while also being part of a community with regular meetings and supported by coaches. The main differences are the programme duration, number of participants, and whether the projects are in a specific theme or wholly formulated by the participants. In this study, both programs are evaluated using similar themes. We analyse this data, and reflect on the context, conditions and design of the programs and our lessons learned from these first experiences.

1 INTRODUCTION

1.1 Recognising, Developing and Rewarding Teaching Excellence

Many universities are looking for ways to raise their ambitions for engineering education. Society is facing complex challenges that are both severe and urgent, which motivates the need for students to learn by tackling realistic problems with interdisciplinary approaches. Another major change driver is digitalisation, which profoundly affects engineering practice, but also engineering education as such. Other issues are more longstanding, such as making engineering education attractive to prospective students, combined with stimulating motivation and retention of the students in engineering programmes. It can be argued, however, that we have come further in identifying what developments are desirable in engineering education, than in understanding how to make them happen.

To enable and drive developments such as these, universities have begun to see the need for faculty to have significant competence in teaching and learning. One implication is that engineering faculty need to be supported in their professional development, another is that the incentive structures need to change so that teaching merits and excellence are better recognised and rewarded.

In contrast to research, teaching merits are perceived by many academics as undervalued in the university career. In the *Teaching Cultures Survey* from 2019, for example, merely 25% of responents reported that teaching is rewarded in the academic career, and 57% even identified education roles as “career-limiting”. Only 25% reported that teaching was very important in promotion to full professorship at their university (Graham 2020). However, the same survey shows an interesting gap, which can give hope for the future. Of the respondents who are in a position as university leaders, no less than 57% think that in the next five years teaching will be more prioritized in academic promotions at their institution.

It is no surprise, then, that university leaders are taking initiatives to make teaching merits play a more important role within promotion structures, and to show that teaching is valued in other ways. In Sweden, about half of the higher education institutions have systems for recognition by awarding honorific titles such as “Excellent Teacher” (Winka 2017). In the Netherlands, there is a particularly strong movement to modernise the system of recognition and rewards. The one-sided focus on bibliometric indicators is challenged, and there is recognition that the academic career system must enable greater diversity, if universities are to achieve excellence also in education, impact, and leadership (Recognition & Rewards 2019; 2023).

One issue that has been referred to as a particularly important barrier to greater recognition of teaching merits is the perceived difficulty to evaluate such merits. As a response, a coalition of universities led by Ruth Graham have developed the *Career Framework for University Teaching*. Figure 1 shows the four levels of teaching achievement in the framework, and the key capabilities that determine achievement at each level. This framework has now been adopted by some 50 universities worldwide, who are systematically sharing and documenting their experiences (Graham 2018b).

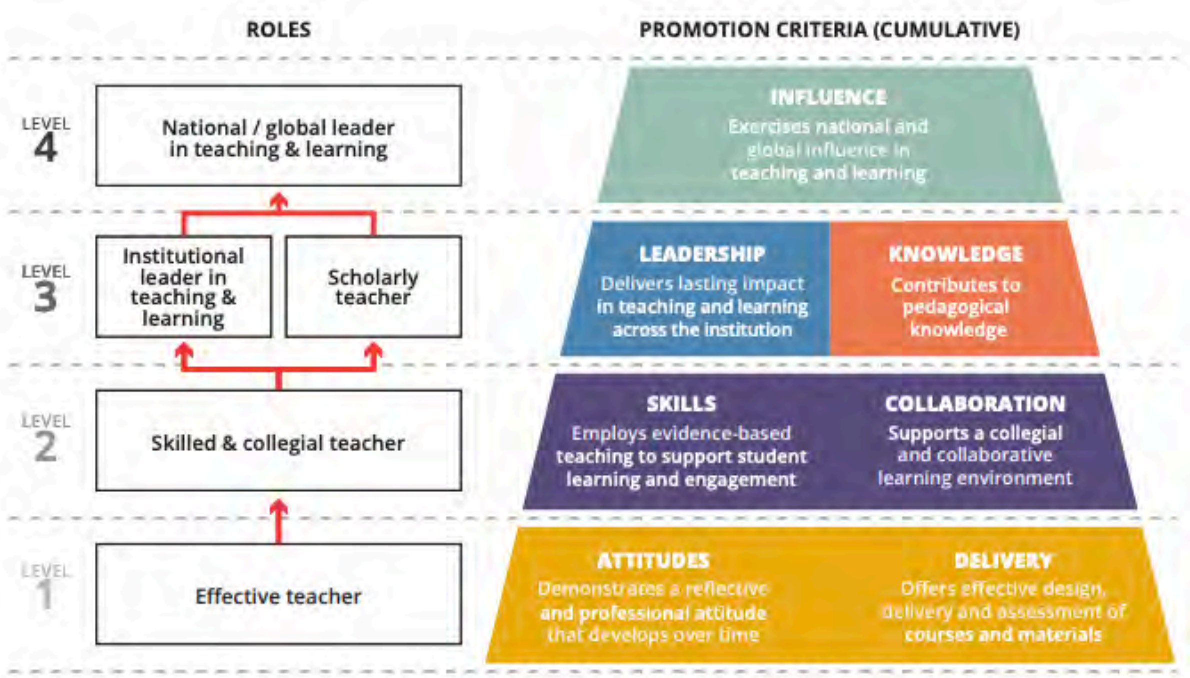

Fig. 1. Career Framework for University Teaching. Developed by Ruth Graham (2018b).

1.2 Teaching Excellence Programmes

It is in the light of this background that we can understand how some universities are seeking new ways to strengthen the collective educational competence of their faculty and promote educational merits and excellence. This study focuses on the experiences of two programmes for recognizing, furthering and rewarding teaching excellence. The universities are located in Sweden and the Netherlands. The programs have somewhat different design although the aims are similar. In both cases, the programs were designed for selecting already distinguished teachers and supporting their continued establishment and visibility as educational leaders.

This positioning of the programs can also be expressed using the *Career Framework for University Teaching*. To be eligible for the program, participants are expected to already be well established on level 1, as *Effective teachers*, and level 2, as *Skilled and collegial teachers*. The aim of the programs is to support the participants in their continued development, empowering them to develop themselves also on level 3, as educational leaders as well as scholarly teachers. Level 3 encompasses both those who have broad and positive influence on the educational environment of their own institution (level 3a) and/or those who make contributions to it the development of higher education pedagogical knowledge nationally and internationally (level 3b). An important feature of the framework is that it is cumulative, meaning that any level also includes those below. Accordingly, the programmes are not meant to prepare the participants for leaving their roles to become “just” leaders. They should also stay firmly anchored in their own teaching practice, as effective, skilled, scholarly and collegial teachers. In the following, we describe each of the two programs in more detail.

1.3 Teaching Excellence Programme at KTH

The programme at KTH came by as a result of internal investigations into how teaching excellence could be better recognised. Awarding a title such as “Excellent Teacher”, which is common in Swedish universities (Winka 2017), was seen as too much focused on past merits. It was more attractive to spend resources in ways that would strengthen participants’ expertise and skills further, thereby also contributing to strengthen the culture and capacity for development at the university. The plans for the programme were presented in 2019. After a long postponement during the pandemic, it opened for applications in fall 2021, with the Swedish authors of this paper commissioned to lead the program.

The name of the programme became *Future leaders for strategic educational development*. The announcement promised that successful applicants could use twenty percent of their time during the year 2022 for their participation. The idea was that the core of the programme was the participants’ work on their own projects, hence the focus and content of the programme was shaped by their interests. In addition, several kinds of joint activities were planned to support their work and to build a community.

Applicants were expected to have substantial teaching experience, i.e. several years, and by the time of application they must also have completed the courses on teaching and learning in higher education required at the university (at least 15 ECTS credits). The application consisted of two parts. The first was a self-evaluation, in which participants should reflect on their pedagogical competence in six dimensions, intended to reflect levels 1 and 2 in the Career Framework for University Teaching (Graham 2018b). The second part was a preliminary project idea, demonstrating their interest and ambitions and discussing how the work would contribute to the university and the participant’s school. Projects should strengthen their own ability to contribute to educational development and innovation at the university, also benefiting their own teaching. The programme received over twenty applications, and a selection of fourteen participants was made by the Vice Rector with input from Heads of Schools and the programme leaders.

It was finally announced that all Swedish pandemic resprictions were to cease on February 9, 2022, and on that very day the program started with a kickoff meeting. Monthly half-day meetings continued during the spring, often containing some input from an expert, group-wise in-depth discussions about the projects, and quick rounds for general discussions. In May the group went on a two-day study visit to Chalmers University of Technology in Gothenburg, the second largest technical university in Sweden. In addition to the programme leaders, participants were supported during the spring semester by a visiting professor in engineering education. After the summer, in late August, the group met for two full days. Then the projects were thoroughly ventilated with critical friends, two who were invited from within the university and two who were national thought-leaders. The monthly meetings then continued until November. Then the focus shifted to reporting the work in various arenas, including a festive poster mingle session in December for guests invited by the participants, and a university-wide conference on Scholarship of Teaching and Learning in March. Participants are still offered support with reporting and publication during 2023, including a travel grant if they wish to present their work in a national or international pedagogical conference.

1.4 Teaching Excellence Programme at the University of Twente

At the University of Twente, one of the (pilot) teaching excellence programmes is a Teaching Fellowship programme. This started in 2021. Each faculty was invited to nominate one fellow, and in addition two senior fellows were appointed. Senior fellows could also be nominated by the faculties but were selected by the University centre organizing the programme. In 2022, the second group of seven fellows started. The Teaching & Learning Fellowship is meant as an opportunity for staff to innovate teaching in an evidence-informed way, meet and learn with teachers from other faculties and contribute to the scholarship of teaching at the university. In this way, participants are meant to be stimulated to pioneer in educational R&D activities that can both advance their own professional development but also help improve education regarding aspects that are on the educational agenda of the university, connected to the university’s vision. The faculty fellows are intended to target their own education and disseminate the results university-wide. The senior fellows are also meant to address impact beyond their own educational setting. The fellowship is not a professional development ‘course’ however, and is therefore also not assessed as such. Apart from the criterion that their approach should be evidence-informed and they should be able to spend one day a week for two years, the only other criterion was to disseminate their findings (e.g., in university events about educational innovation and/or teaching excellence, at conferences such as SEFI or national conferences, in education meetings or study days). To support knowledge exchange and community feeling, each group had a common theme: for the first group, CBL had been set as a common theme in the call for fellows to the faculties, in the second this was digitalization. To support the fellows in their activities, we did provide the resourses to meet (every 6-8 weeks) in a coffee and/or lunch meeting to share knowledge and experiences and work on collaborative goals, if applicable. They also had a coach and had the opportunity to discuss their plans and progress or ask questions about evidence-informed teaching practice both to a coach and the centre leader. They received support, for example, in obtaining ethical consent for their study with the university's ethical committee if desired. Faculties were free to select candidates using their own procedure, given the main criteria/recommendations in terms of time spent and main goals. We recommended the Senior University Teaching Qualification[2] as prior experience, but this was not mandatory.

Fellows are expected to spend (on average) one day per week on their fellowship for 2 years. They may use the title of their Fellowship for an additional year for dissemination purposes.To determine how the Fellowship programme should be continued after these first pilot years, an evaluation study was carried out.

2 METHODOLOGY

2.1 Evaluation Study KTH

The evaluation of the programme at KTH started mid-way through the programme with one hour of joint reflections with the whole group during the two full seminar days in August. A few weeks later, programme leaders made written reflections. After the formal activities in the programme were concluded, an online survey was sent to the participants (early April 2023). The survey consisted of several statements for quantitative rating that were copied from the survey at University of Twente, or formulated to be as similar as possible. Some questions were added, especially to prompt for more qualitative reflections. Participants were informed and asked for active consent to use their responses in this study. Further written reflections were made by the programme leaders, as part of writing this paper.

2.2 Evaluation Study – University of Twente

The evaluation study at University of Twente combined an online survey with interviews and document analysis. For this paper, the first cohort of fellows was surveyed one year after the start and two years after the start; they were also interviewed twice in relation. The second cohort was surveyed and interviewed once. In addition, documents (e.g. plans, outcomes, tools) were requested as data, and other stakeholders, such as education directors at each faculty were also respondents in individual interviews.

The online survey was used to gather data about their *satisfaction* with the fellowship programme (scale 1-5). Questions concerned, for example, their extent of engagement with the fellowship and how interesting they found it. In individual interviews, participants were asked to clarify their answers more in-depth. The interviews were also meant to discuss participants' *learning*, if available related to any documents participants' had shared. Documents could also be shared in a later stage in relation to participants' planning for their fellowship. The interviews and documents (e.g., presentations, publications, tools) were also used to show the way in which

[2] https://www.utwente.nl/en/learning-teaching/professional-learning-development/sutq/

learning had been applied by the participants, and whether there were already contributions at the level of student outcomes and/or organization.

The study was approved by the ethical committee of the university (req.nr. 221067) and informed active consent was obtained from all participants for the study.

3 RESULTS

3.1 Lessons Learned at KTH

A rewarding experience and a learning community – In the survey, participants report that their experience in the programme as very rewarding. Six statements about engagement, learning, usefulness and satisfaction received an average rating of 4,6/5. They are also enthusiastic about recommending the programme to a colleague (4,7/5). Participants valued the community very highly. Three statements about getting to know the others, sharing knowledge and experiences, and being stimulated by the others' projects were rated 4,7/5 on average. The programme leaders confirm that they too felt a strong sense of community. This aspect should be considered important when designing any future programme.

The projects – Participants mainly rated *their own project* as well chosen (4,0/5), and agreed partly to statements about the benefit of carrying out the project within the programme and that they felt supported in the programme (3,9/5). Fewer participants reported practical collaboration with other participants. Two statements about working together in their projects, or meeting outside the programme were rated 3,3/5. One participant says: "*The difference in the projects and background of the participants did not favor spontaneous cooperation. Still I had some informal exchange with some colleagues, especially following my feedback to their work*." Another makes a suggestion: "*Create sub-groups that are more 'thematic' so that we keep the ball rolling with peer support (or peer pressure...)*". There were plenty of critical comments about the overall set of projects, finding some too big and broad while others were too specific to a particular teaching context. The programme leaders saw that there were several suitable and successful projects, but for future programmes, all projects should be selected for their strategical relevance, general interest, or at least have more in common. It is also important to select projects that can benefit from being in the programme. If the work can just as well be done on one's own, the programme risks becoming more of a distraction.

The programme activities – Participants show high appreciation of the amount of activities, the monthly meetings, and the two days in August, with average ratings of 4,5/5. The outstandingly most appreciated activity in the whole programme was the study trip to Chalmers (4,9/5). The two days focused on topics of high relevance for the projects. In particular, it showcased areas with important differences in how education is organised. This offered a highly interesting contrast and made a strong impression on the participants. One voice: "*The trip to Chalmers was a true highlight. This trip was the best part of the program, and has been very valuable to me for the long-term development of my role at KTH*." Travelling together was also positive for the group cohesion. The study visit invited reflections about how things work at KTH, something that could have been more present in the programme. One participant reflects: "*I would like more discussions about the management of KTH as well, the roles on all levels, how we manage education.*" Another aspect is the input from experts, both internal and external, which was much appreciated. Their presence created a "sharper" context, which had positive influence. If the program is to be implemented again, the presence of critical friends in the activities could be more accentuated. Regarding the programme year, one participant usefully suggests more intense activities in the beginning: "*More activities in the first few months would make everyone jump in with much more energy and get momentum. More frequent interactions and discussions can expedite getting over the first stages of confusion*."

Planning, time and resources – The participants were accepted at the end of December, and many participants had difficulty setting aside time already during the spring term. Clearly, the process of announcing the program and making selections needs to start much earlier, giving participants a planning horizon of at least six months. Further, when the programme was announced, it was promised that the participant would be able to spend 20% of their time for their participation. In reality, it turned out that, with only a few exceptions, participants had to squeeze the work into their existing time. The background was a conflict regarding the programme between President and School level, exacerbated by the time pressure when deciding to open the programme. Many participants commented on this: "*Regarding funding and time, a premise before the program was that 20% would be given, but then it seems that no level really wanted to take these costs, so it fell on my division anyway, which meant that no extra time could be given. Of course, it meant less focus and lower quality*." If the programme is to be run again, the necessary resources must be safely secured and promises kept.

Number of participants – There were fourteen participants admitted, but after two drop-outs (one after three months and one after eight months), twelve people completed the programme. Some participants have commented that the group was too diverse in their background understanding of teaching and learning: "*Some colleagues would have benefited from some 'recap' of the main pedagogical concepts underpinning their projects*". With fewer participants, each project can receive more attention and support, meetings can be more focused, and crosstalk between the projects can increase. It might be easier to secure the necessary resources. Exclusivity may also increase the merit value of being selected and of participating. If the program is to be carried out again, we suggest a smaller group, perhaps five to eight participants.

When asked if the participants would recommend the university to continue the program, they agree to a high degree, 4,4/5. To summarize the evaluation above, if the program is to be implemented again, some key recommendations are: longer planning horizon and more reliable resource conditions; projects should address a theme and be more strategically interesting so they benefit the university more broadly; more exclusive selection. Regarding the design of the program activities, the format can be developed based on the experiences during the first cohort.

3.2 Lessons Learned at University of Twente

Most participants in the fellowship (partly) agree (score of 4 or 5 out of 5) that their fellowship is interesting, engaging, and that they benefitted from it, for example, at the satisfaction level. They are (very) satisfied about the supportive atmosphere in their Fellows group, for example. "*I learnt a lot and exchanged ideas*", one fellow reports, and examples at the learning level are about knowledge about the theme (e.g., CBL) and its applicability, but also about systems and support at the university. Most first cohort fellows reported they had already changed their teaching as a result of the fellowship; the second cohort reported to be in progress with this.

Although all survey answers were generally 'neutral' (3) or (very) positive (4-5), the question about receiving support to change/improve their teaching was answered least positive; at the same time, for most change/implementation was also still work in progress or at least not yet entirely completed. At the organization level, Fellows gave examples of having become part of a steering group, or playing a larger or more explicit role in their within-faculty teaching community.

Feedback about the programme concerning coherence among topics (in relation to the common theme), visibility, institutional support and change processes was offered. According to the interviews, differences among educational programmes were noticed by the fellows, also in relation to their colleagues' perception of the fellowship themes: "*I think in that regard we could also support each other*". A '*feeling of belonging*' is mentioned. The network aspect appears to be mostly about sharing, exchanging and feeling supported as part of the group of fellows. Answers about support from their own colleagues or relevance of their work for colleagues are more neutral. Moreover 'time', also in terms of run time, was mentioned as challenging.

The education directors were mostly positive in their perception of the fellowship programme. They all felt, for example, that it should be continued after the pilot period. At the same time, they were all reflective about how fellows could be more supported (both by the directors themselves as in general) to fulfill ambitions both at the individual and faculty level. Community, visibility, and fellows as '*innovation brokers*' were addressed more explicitly with the education directors than apparent in the perceptions of the participants. In line with most of the feedback aspects of the fellows, however, education directors offered feedback to enhance selection and theme (balance of common theme with faculty connection and individual interests), visibility, brokerage (i.e. to support knowledge sharing, networking, about evidence-informed teaching innovation) and related support for fellows, as well as attention for time pressure and recognising and rewarding teaching. The fellowship provides input for further developing recognising and rewarding at the university.

4 DISCUSSION

By analysing these programmes side-by-side, we already have some initial improvement ideas based on these preliminary findings. For instance, we see a clear advantage with having an overarching theme for the participants' projects, connected to the university's education vision, however: balanced with faculty and participants' own interests. The thematic proximity can create better potential for collaboration between the projects and thus strengthen the sense of community even further. It can also be expected to enhance the learning, when similar topics are eplored through slightly varying perspectives. It could also make the resulting group expertise more recognizable to colleagues. Time is always a challenging factor in professional learning (Gast et al 2017), even if facilitation is (meant to be) arranged beforehand. Apart from communication about facilitation requirements, providing actual solutions to time pressure problems might be more fruitful, and is work in progress in these programmes.

This evaluation is an attempt to record the first impressions of the process by soliciting the experiences of those who were directly involved as participants or facilitators. It is important to note, however, that the full impact of initiatives such as these can only really be seen in the longer term. It is then also important to consider the impact achieved in the light of the broader conditions for educational development at the institution. To be able to ultimately achieve teaching innovation, teachers need to develop the related knowledge, skills and attitudes; they must also have the opportunity to apply this in practice. According to Desimone (2013; also referring to Kirkpatrick 1996 and Guskey 2022) subsequent levels of professional learning effects depend on teachers' satisfaction with their programme, their learning, and subsequently application.

At the same time, the programmes also have other forms of impact. Changes at the organizational level might be initiated because of, in interaction or along with programmes such as these. Participants are extending their sphere of influence, for example, provide input regarding how education is organised or how teaching is rewarded in the academic career system, or they may be consulted by others in relation to teaching innovation at team, department or faculty level. In relation, to more fully benefit both at the individual and organizational level of these programmes in terms of participants' development as scholarly and leading teachers, universities' framework for recognistion and rewards need to be further developed to align with these programmes.

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DEVELOPING TEAMWORK SKILLS THROUGH SIMULTANEOUS GROUP PROJECT COURSES (RESEARCH)

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ABSTRACT

The popularity of project-based learning (PBL) has led to a situation where engineering students take several group project courses at the same time. From a student perspective, this can generate considerable issues. Previous research has indicated that already single PBL courses can be challenging, especially time and task management-wise and intuitively overlapping PBL courses compound this complexity. As existing literature on this topic is relatively sparse, the goal of the present study is to examine what kind of student challenges simultaneous PBL courses generate, how students navigate those and what kind of additional learning can it foster. The results should help PBL course teachers to consider the impact of overlapping PBL courses from a student perspective and provide better support for them.

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1 INTRODUCTION

Teamworking capabilities as transferable skills are generally considered highly critical for engineers [1] and project-based learning is one method for integrating them into the curriculum [2]. While extensive research on project-based learning and teamwork-related aspects to it has been conducted, there are still many things we don't know [3].

As group projects have become more widely used in engineering education, students are more likely to find themselves in situations where they have to take part in several group projects at the same time. Research on organization science has indicated that multiteam membership, that is, being a member of several teams at the same time can either increase or decrease learning and productivity both on the individual and team levels depending on the context [4]. This implies that simultaneous group projects can be either an opportunity or a threat in the engineering education context, warranting the need for further research on the topic.

Against this backdrop, we examine in this study what kind of challenges and benefits simultaneous group projects generate for engineering students in terms of teamwork skills development. Our dataset consists of qualitative interviews among engineering students in a northern European university. The results suggest that taking several PBL courses simultaneously seems to generate a variety of social, interactional, cognitive, and emotional challenges, which students try to manage, especially with the help of productivity tools and strategies and planning ahead. Based on our observations, we suggest some interesting avenues for further research.

2 PROJECT-BASED LEARNING AS A CONCEPT

Project-based learning (PBL) refers to a method of learning where students work in groups on self-directed projects based on real-world challenges and participate in formulating the problems they aim to solve during the project themselves [2, 5]. PBL as a learning approach has received wide popularity in engineering education in the past decades. This is because PBL has been associated with such desirable outcomes as better employability of graduating students, higher learning motivation, and fewer drop-outs [6]. PBL also has been found to support learning generic practical skills necessary for work-life like project management and communication and collaboration skills [6]

Interdependencies between separate project courses have received scholarly attention mainly from the perspective of curriculum development. Since PBL as a learning method requires certain skills and understanding from the learners, there should be a clear structure and plan on how PBL-based courses are implemented in the curriculum and what are they focused on to enable students' longitudinal development [3]. One should have a meaningful mix of projects that focus on building more discipline-specific skills and knowledge through well-defined problems and those where more generic skills are learned and students work on more open-ended problems [7]

3 STUDENT CHALLENGES IN PBL

While in general students tend to enjoy PBL-based learning [5, 8], previous research has identified a number of potential challenges in PBL from the student perspective. Students can perceive learning less in terms of domain-specific engineering and science competencies compared to more traditional theory-based teaching [6]. This is perhaps because integrating in-depth natural science-related learning into group project-based teaching can be challenging [5].

A variety of specifically teamwork-related challenges have been observed in previous literature as well. Teams might have free-riders, those who lack time management skills, and people disinterested in the project topic which can cause challenges [8]. It is also possible that despite being technically assembled in teams, students don't actually work as a team. Instead, they might delegate work tasks and work on them in silos without actually collaborating, which can lead to work quality and organization issues [9]. To make sure that the team is organized, individual students might end up in a position where they perceive themselves as forced to take on a leadership role to activate those members who are less active and talkative than others [8]. Especially if the team is multidisciplinary, it can also be difficult for individuals to identify with others, which is problematic for team dynamics-wise [10].

Most studies related to PBL focus on the level of an individual course [3]. However, project courses do not take place in a vacuum. Instead often engineering curriculums are designed so that students take several courses at the same time and they of course have other personal commitments as well. In terms of the student experience, the implications of this are also important to understand. Some findings on the additional challenges that issues external to a specific team project course can cause are also found in existing research. Crichton et al [8] also noted in their research how working simultaneously with studying and other ongoing courses might cause challenges in terms of getting the team organized and performing well. Such other commitments and things like extracurricular activities or voluntary assignments easily lead to situations where finding a common time to work on the project is hard [11]. While these are important findings, for optimizing the student learning experience, further understanding of this topic would be beneficial.

4 MULTIPLE TEAM MEMBERSHIP AND ITS IMPLICATIONS FOR PBL

Multiple team membership refers to situations where an actor belongs to several project teams at the same time [4]. This topic has been recently gaining increasing attention in the field of organizational science since work in companies and other organizations are increasingly being organized around teams. Further, it has been shown that nowadays organizational members tend to belong to not only one but several teams at the same time [12, 13]. This can be challenging for the individual in a variety of ways. Especially in the beginning, it can place a considerable burden on one's psychological resources [14]. Further, cumulative workload from different teams ends up exceeding individuals' capacity and it can lead to people prioritizing certain teams and neglecting others [15].

It would however be shortsighted to see multiple team membership only as a negative thing [4]. Being exposed to different types of work practices increases the likelihood of recognizing improvement or change potential in one's own practices [16], meaning that Individuals can learn something new and useful from each team they belong to [15]. It also can support individuals build their social networks, which is beneficial in many ways [14].

In summary, PBL as a method has been found particularly effective in terms of supporting learning teamwork and collaboration skills. Further, multiple team membership can support learning new things by being exposed to different types of teams, individuals, and practices. This raises the question of whether working simultaneously in different PBL-based courses in different teams could facilitate students' teamwork-related learning. Or would in such a setting the potential issues of multiple team membership end up leading to bad teamwork experiences and thus impeding learning?

Since many engineering students are already facing this situation during their studies where they need to participate in several PBL courses at the same time, further understanding on this topic would be important. With this in mind, the present study aims to explore this topic through the following research questions:

1. What kind of challenges do students that take several team-based PBL courses end up facing and how do they manage these challenges?
2. What kind of additional learning can simultaneous PBL courses provide for students?

5 METHODOLOGY

The research questions were addressed with a qualitative interview study in a Northern European university. The present paper is based on interviews with 9 engineering master's students who had participated in two or more temporally overlapping PBL courses during the same semester in the past 12 months. Informants were recruited by approaching students of two selected PBL courses, where it was known that many of the participants were likely to take other PBL courses at the same time. Participants were provided a 10 euro gift card as a reward for their participation.

The interviews were semi-structured in nature and lasted on average around 1h. The interview questions aimed to understand 1) what kind of groupwork-based PBL the informant had taken in the previous 6 months, 2) how did the projects unfold, 3) what kind of teamwork-related challenges did the informant experience as well as 4) what kind of additional challenges and learning did participating in multiple PBL courses at the same time bring to them.

For analysis, an inductive analysis process [17] was followed, drawing from the principles of grounded theory [18]. As such, analysis was mainly driven by patterns observed in the empirical data, without trying to connect it immediately to existing theoretical frameworks. More specifically, transcripts of the interviews were first read through. After this, transcripts were thematically coded with three categories to identify parts of the interviews that were relevant to the research questions: 1) statements related to challenges generated by multiteam membership, 2) statements related to managing challenges of multiteam membership, and 3) statement related to learnings generated by multiteam membership. Next, statements for each code were open-coded to observe patterns in the data (for example: "No time to take care of wellbeing" or "Many meetings in a row"). In the final third step, open codes under each theme were examined and combined into broader abstract categories in the spirit of proceeding from open coding to axial coding [19]. At this point, findings were also compared to previous literature on the topic.

6 RESULTS

6.1 Challenges associated with multiple team membership

Informants reported a variety of different challenges related to multiple team membership from participating in several PBL courses at the same time. Drawing from Järvenoja et al [20] the challenges have been grouped into cognitive, emotional, and social & interactional challenges. Cognitive challenges refer to issues in understanding or being able to complete project tasks, emotional challenges to experiencing negative emotions and discomfort during the project, and social & interactional challenges to issues related to different working styles, communication, and context-related issues [20].

In terms of cognitive challenges, the most prevalent issue for the students was keeping track of what is happening in each team and what needs to be done for each course. One of the informants reported for example how just remembering which topics had already been addressed in which group was difficult:

> *"it takes your focus also away when you have multiple groups at the same time, you're not able to concentrate because you forget. What did you discuss in that group? What did you discuss here? So things get a little mixed up"*
>
> *Informant #9*

While similar issues can be associated with any kind of course, the problem was perceived to be amplified by the PBL setup, since in such courses more independent thinking and planning are needed as course tasks are less specific in terms of how they should be approached. This lack of big-picture understanding resulted also in small practical issues like forgetting meetings or missing small course deadlines.

Social and interactional challenges were reported by the informants as well. Because of other PBL courses and personal obligations, it was difficult to schedule meetings for discussing the project and working together. This led to situations where one had clashing meeting times between different projects making equal participation in everything difficult.

Even if it was possible to find distinct time slots for meetings of each team some problems remained. Often it meant that one could have meetings from different teams in a row, which was perceived as draining in itself. Having to switch contexts quickly from one project to the next amplified the cognitive challenges of staying on top of what is relevant for each project.

The constant context-switching also leads to a variety of emotional challenges, including feelings of being lost between the courses. Finding common meeting times required making personal compromises such as running from one meeting to the next or meeting late in the evening. This lead to sentiments that other team members don't care about your personal well-being or fail to recognize and appreciate the other commitments and responsibilities that one has. Enforcing personal limits in terms of contribution or participation because of the other pressures in turn created feelings of inadequacy and being left behind.

At the end of the project – we had this [another course] two weeks before the last presentation where we had to, attend the [other] classes. So we were meet me and my friend were a bit left over in the work and the progress done during those [final] two weeks.

Informant #1

6.2 Managing issues of multiple team membership

In terms of different ways to manage challenges caused by multiple team membership, three different types of strategies could be identified in the data.

First was prioritization. Some informants reported directing most of their effort into courses that they perceived to be the most meaningful to them. They still contributed to other courses, to respect the commitments they had made for the other team members and course in general. However, they reported not putting in the same amount of effort as in the courses they perceived most interesting. Also, some students prioritized those projects where they had been assigned a specific sole responsibility in the team compared to teams where their role was broader and more generalistic.

The second strategy was using productivity tools and techniques to combat especially cognitive challenges of multiple team membership. Some informants used to-do- and list applications like Trello to map their tasks for each course. Others conducted very diligent note-taking or separate Microsoft Teams channels to keep on track of what was discussed and happening in each team. To make getting quick answers from all team members and finding common meeting times easier, some reported using polls in mobile chat applications so that communication overhead would be reduced.

The third strategy was planning ahead and being organized. This could concretize for example in doing one's utmost to have meetings of different teams on different days to combat cognitive challenges. Some set internal deadlines for themselves that were tighter than official course deadlines to make sure personal workload was more evenly distributed in cases where deadlines in different courses would have otherwise been overlapping.

There were also those students who did not really feel like multiple team membership was creating such problems that explicit managing efforts were needed. This was especially the case if the course structures of the simultaneously ongoing PBL courses were well aligned and for example, big assignment deadlines were not at the same time. Flexible teammates who didn't have their calendars completely full helped here also.

6.3 Additional learnings from multiple team membership

The main benefits informants perceived to gain from multiple team members in terms of additional learnings related to enhanced teamwork capabilities and recognizing one's capabilities in different roles.

In terms of teamwork capabilities, being able to simultaneously witness different leadership styles and dynamics in different teams helped form an understanding of what kind of leadership behaviors and structures support good performance and team dynamics. This included for example learning how to effectively delegate tasks and activate less active fellow students. Several informants also reported understanding now the importance of having a distinct leader in the group.

Many informants also noted learning to work in different kinds of roles and sharing responsibility. This included more functional roles like if one usually was responsible for doing presentations and giving these tasks to others to support the learning of others. Team dynamics-related roles were also mentioned, like switching from a follower role to more of a leadership role or from an active ideator role to one where one gathers ideas from others. Sometimes these role switchings were rooted in personal interest, but sometimes it was not particularly desired. One might end up being in the leader role mostly because nobody else was willing to take it and the team wasn't making good progress. Some informants also reported learning tenacity: having to work and finish things even in a situation where one doesn't enjoy the team or the project that much. Others reported learning nothing additional.

A few cases where individuals attempted to take good practices or learnings from one team to another were also presented in the data. One informant reported learning an effective feedback-providing method in one course and utilizing it in another struggling team successfully. Another described getting certain critical feedback in one course from her team members and because of that changed her behavior not only in the team that provided it but also in other teams she was working in concurrently. Third informant particularly enjoyed certain ideation methods in one PBL course, and utilizing them in another PBL course. There was also a case where a student learned an interesting analysis method in one course and tried to bring it to her other team, but the team rejected it which felt frustrating for the individual.

7 DISCUSSION

The present study contributes to the literature on student challenges in PBL education [3, 7]. More specifically the findings extend learnings from previous studies that have examined the student experience of PBL courses [8, 11] by going beyond the traditional single course focus and providing information on what kind of distinct challenges, benefits, and learnings participating in several PBL courses at the same time bring to students.

In terms of challenges that students face due to multiple team membership caused by simultaneous PBL courses informants reported different cognitive, social & interactional, and emotional challenges. Most prevalent cognitive challenges related to having a solid big-picture understanding of what is happening in which team and what are the most pressing tasks to do in each course. One observed way to solve this issue was by using productivity tools and techniques to stay on top of what needs to be done and what has been discussed in each team.

The main social and interactional challenge was the difficulty in finding meeting times as everybody in the team had also other courses (PBL and more traditional) and commitments that they needed to attend to too. This led to difficulties in putting equal effort in all the teams and having days full of meetings the latter of which led to further cognitive challenges. To combat this, students prioritized their participation in more interesting courses or just pushed through the challenges. The need to stretch one's capacity in turn created emotional challenges of not being able to take care of one's well-being and feelings of inadequacy.

These findings are in line with Crichton et al. [8] and Hussein [11] who observed how students in PBL courses can face scheduling challenges due to competing commitments, like other courses and working while studying. The present study's findings suggest that if those other commitments are other PBL courses, the situation can be particularly tricky since this scheduling-related overhead comes on top of cognitive challenges related to keeping track of what is happening and needs to be done in each distinct project. As such the results extend current scientific understanding by providing a more nuanced understanding of student challenges in simultaneous PBL courses and how those challenges can be managed.

In terms of learning, multiple team membership allowed students to witness different kinds of team constellations and dynamics. This led to recognizing leadership styles and practices one felt produced the best results. Interestingly, these leadership style-related observations seemed to usually favor the more traditional single-leader type of arrangement rather than shared leadership inside the team. This finding is interesting since in terms of team structure, none of the PBL courses that informants took suggested selecting a distinct project manager. On the contrary, one course that 8 of the 9 informants took, specifically tried to structurally enforce shared leadership by requiring rotating leadership-related roles inside the team.

Considering the fact that the need for traditional manager-led teams and organizations is being increasingly questioned in contemporary organizations [21], this raises the question is it actually a good thing that students learn to prefer teams with traditional single-leader arrangements. However, considering the observed cognitive and social & contextual challenges related to simultaneous PBL course experiences, it does feel relatively intuitive that from the student perspective, teams where there is a clear and diligent leader are easier project contexts. With this in mind, it would be highly interesting to explore in future studies how shared leadership based team arrangements could be encouraged and fostered in contexts where students take several PBL courses at the same time.

The present study naturally has its limitations. Most obviously the dataset is relatively limited in terms of the amount of informants. However, the research project these findings are building on is still ongoing, and further interviews are planned. In addition, the dataset primarily consisted of informants from international backgrounds, specifically those of African, East Asian, and South Asian heritage. Several of these informants reported perceiving strong cultural differences in terms of how students from different countries approach studies and prioritization strategies related to simultaneous PBL courses. Thus, a study with a broader dataset in terms of the cultural background of informants could provide interesting additional observations related especially to strategies in managing multiple team membership. Finally, the present study looked at the phenomenon from the perspective of individual students. It could be particularly interesting to try to understand how PBL teams as collectives build practices and culture that fosters negotiating and compromising time and task management that alleviates challenges caused by individual commitments that each team member has.

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DC Grid Power Congestion Management Laboratory Experiments

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In the process of the electrical energy transition, a new curriculum for bachelor electrical engineering is developed. A new development is DC grids, as they are shown to be promising in solving the power congestion management problem. Particularly when adding solar power, battery storage, and load appliances including power electronics, DC grids are replacing AC grids, especially in micro-grids.

The development of new laboratory experiments using three educational methods is described in this paper. First, theory combined with online calculation tools is used to prepare the students for the subject. Second, the experiment has to be prepared using simulation tools, and third, the experiment is conducted using a hardware trainer, specially developed for DC grid education.

The purpose of laboratory experiments is to learn how power congestion management is regulated in a DC grid. For this, students have access to a Grid Manager, with a current control add-on. This so-called Droop Controller enables the control of a bidirectional current flow.

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There are four learning objectives. 1-Control voltage level, 2-Control current level, 3-Regulate output power from a Grid Manager, 4-Regulate bidirectional power flow using emulated appliances. These learning objectives are spread over four weeks.

Students will first learn the basics of the grid manager. They will learn how to control the voltage in a DC grid in week 1. In the second lecture, they will use a current controller and notice a difference in controlling the output power while maintaining a stable output voltage. In Lectures 3 and 4, the grid manager and droop control with bidirectional power flow is explored.

The outline of the lectures and experiments is presented in this paper as well as the minimum requirements that students must meet.

1 INTRODUCTION

Since DC power [1] is independent of frequency and phase, it can therefore be utilized easily for a single reason. There is no need for complicated AC synchronizing techniques to make full use of renewable energy sources. Another reason is that most appliances are already DC-powered. Since power congestion management is easier to implement in a DC grid [2, 3], it can be favored over AC grids. For controlling the power flow in a DC grid [4], new techniques such as droop control [5], are being developed. Power consumption can be made dependent on the variation of the voltage in the main power grid. This dynamically assists in keeping the power grid in good health and prevents critical applications from failing. The application of droop control in DC grids is discussed in [6, 7, 8]. An experimental setup was created [9, 10], for doing experimental work in low voltage DC grids [11]. It includes power electronics educational training laboratory exercises [12, 13]. A DC grid manager with training software [14] is presented in [15].

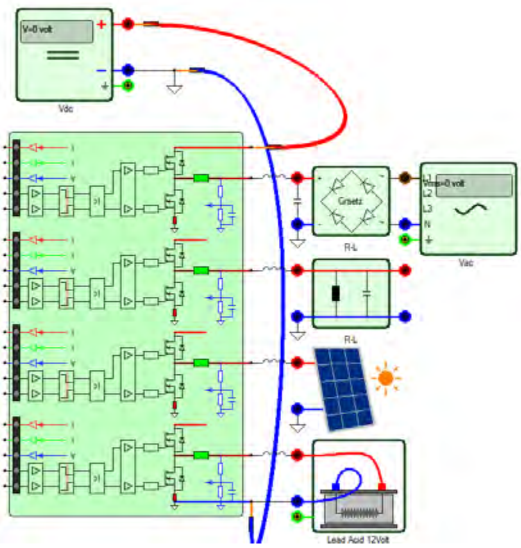

Fig. 1. Grid Manager Hardware

In section 2, an introduction in the methods and tools is given, which is used to achieve the four learning objectives. The four learning objectives are explored in section 3, 4, 5 and 6. An optional assignment on power congestion management in DC grids, is discussed in section 7. The results and minimum requirements are discussed in section 8.

2 OBJECTIVES

The aim of the laboratory experiments is to learn how power congestion management is regulated in a DC grid. For this, the students have access to a Grid Manager, see figure 1, with current control add-on. This so-called Droop Controller enables the control of a bidirectional current flow.

There are four learning objectives.

1. Control voltage level
2. Control current level
3. Regulate output power from a Grid Manager
4. Regulate bidirectional power flow using emulated appliances

The basics of the grid manager, see figure 1 is the first subject, the students encounter. First voltage control in a DC grid is explored in the first week. In the next week, current control is applied and the students should observe the difference in controlling the output power, compared to voltage control.

Using simulation and tooling, see figure 2, the basics of using switched mode power supplies in the DC grid is explained. Using the tool, the basics of the wave forms that will be measured are explained.

Fig. 2. Tool [14] to study the basics wave forms of switched mode power supplies.

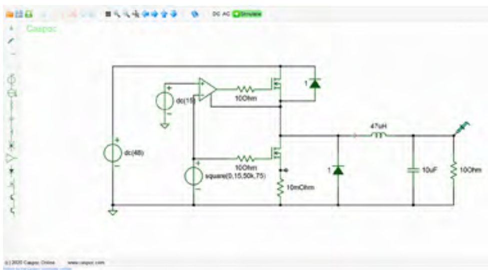

Fig. 3. Online simulation [14] of the synchronous Buck converter..

To understand the operation of the semiconductors inside the switched mode power supply, the students have to study the internal working of the applied synchronous buck converter. For this the online simulation is used, see figure 3, as it give insight into the influence of the switching frequency, duty cycle and blanking time in the applied gate controlling signals.

To prepare the students for the experiment, the laboratory set up is simulated as a digital twin, see figure 4. All connections and external devices that are connected to the Universal Four Leg [2, 3] are available in the simulation [14]. Students can practice the connections they have to make in the experiment.

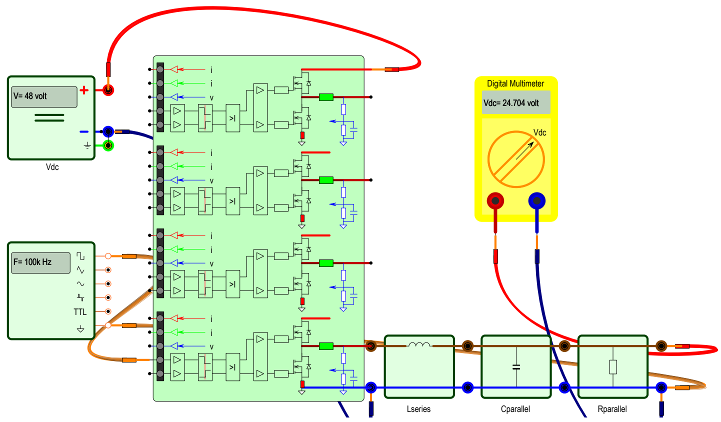

Fig. 4. Simulation of the Universal Four Leg configured as a synchronous Buck.

Students have to measure the relation between the duty cycle and the averaged output voltage. Adding inductance at the output reduces the output voltage ripple. Adding a capacitor at the output, reduced the output ripple even further.

In the first lecture, the students will learn about the basics of the DC grid. Using an online simulation tool, they will learn how power electronics is used. A basic switched-mode power supply is studied using simulation. The differences between the most basic configuration of a buck converter compared to the synchronous buck converters, are explained using the software.

In the next lecture, current control is added and students will see the improvement over voltage control. After practicing voltage and current control, in week three, the students are given the typical example of a Grid Manager. The DC Grid voltage is used to control the amount of power that is regulated into each load of the grid manager. During this laboratory, the student will practice voltage, current and power measurements. The principle of droop control is introduced this week. The parameters of the droop characteristics are programmed, and by varying the DC grid voltage, the loads are regulated according to the programmed droop characteristics.

The last laboratory emulates four appliances connected to the DC grid. Each appliance has a typical droop characteristic programmed and all appliances are connected to the same DC grid. The Universal Four Leg emulates four appliances. Since the appliances are either consumer or producer, the Universal Four Leg is operated in bidirectional current control mode.

3 WEEK 1: INTRODUCTION HARDWARE, VOLTAGE CONTROL

In this laboratory, the students are going to explore the functioning of the DC grid. A very basic first introduction in power electronics switched mode power supplies is given using simulation. Using the simulation, see figure 5, the basics of controlling voltage in a DC grid is explored.

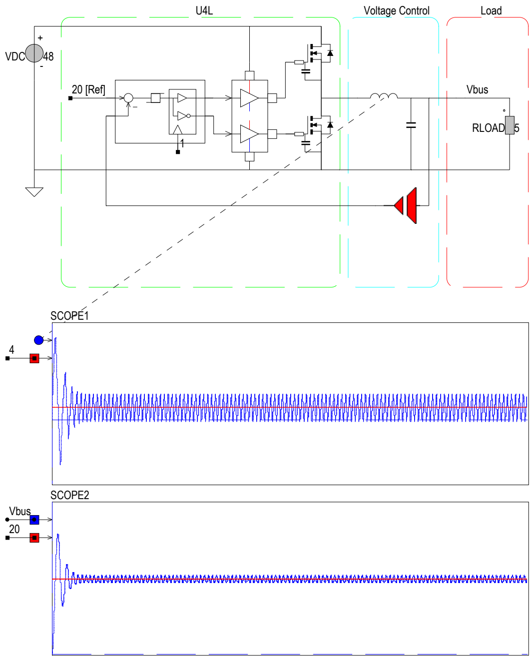

Fig. 5. Voltage control.

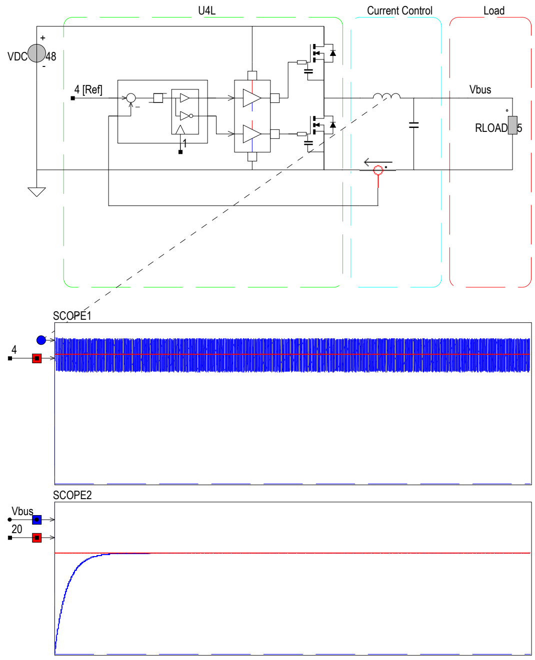

Fig. 6. Current control.

4 WEEK 2: INTRODUCTION HARDWARE, CURRENT CONTROL

In the second laboratory, the students have to practice the use of current control to regulate the flow of power, see figure 6. Again using online tooling and inline simulation and finally the simulation using the digital twin prepares the students for the experiments.

5 WEEK 3: GRID MANAGER DROOP CONTROLLED OUTPUTS

The previous two laboratories were mainly teaching students the basics of the applied hardware. In this laboratory the students will meet the first use of the Universal Four Leg as a Grid Manager, see figure 7. The input DC Grid voltage to the Grid Manager can be varied using the power supply bench. The droop characteristics are programmed inside the universal four leg. There are four passive loads, that will be powered from the grid manager according to the droop characteristics.

The main part of the laboratory experiment will be programming the droop characteristics and confirming them by measurements.

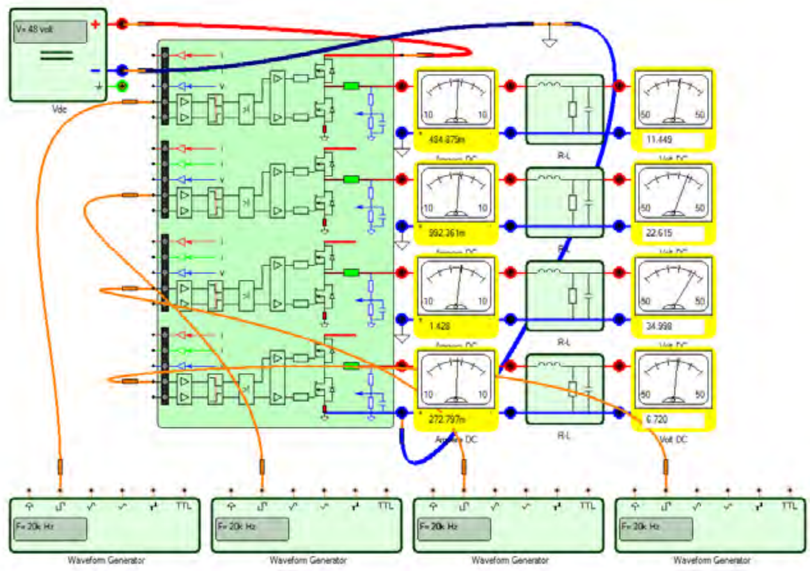

Fig. 7. Universal-Four-Leg configured as Grid Manager

6 WEEK 4: EMULATING DROOP CONTROLLED APPLIANCES

All the ingredients for power congestion management in a DC Grid, are explored in the previous laboratories. In this laboratory, the students have to create a DC Grid with four emulated appliances, see figure 8. This configuration enables bidirectional power flow which allows students to see the behavior of a dynamic system. The Universal Four Leg is used to emulate the four different appliances:

Battery (Storage)	Solar (Producer)
Load (Consumer)	External Grid (Power Exchange)

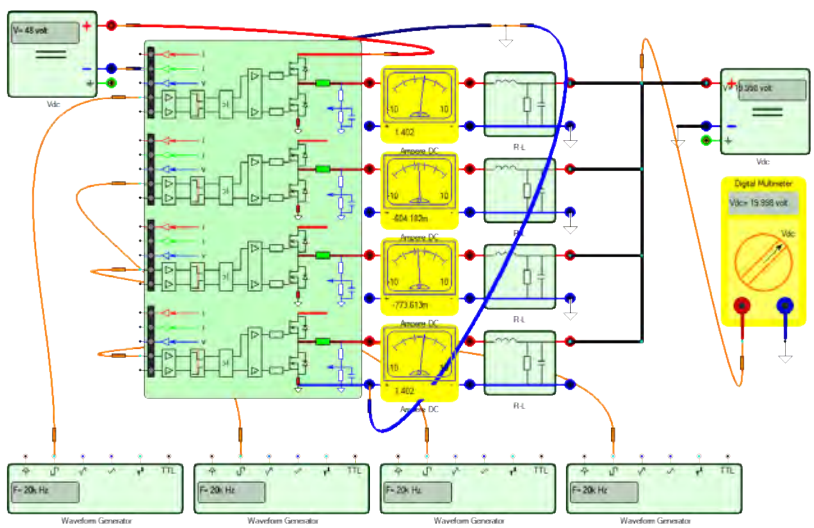

Fig. 8. Universal-Four-Leg configured as appliance emulator

7 OPTIONAL ASSIGNMENTS: POWER CONGESTION MANAGEMENT

With the U4L per group, and a long main cable through the lab, we can connect a number of students with their U4L with droop control. They can send the power control signal either manually or via the Arduino.

The assignments include different subjects, like manually adjust a set point, and then view the power balance between the various connected groups. The different groups are then subdivided into solar panel, battery and consumer, each with its own function.

In the first assignments, the students adjust the droop controller manually. In the following assignments, the students program the droop characteristic, see Figure 9, into the Arduino. In this assignment, the maximum source current is 5 ampere and the nominal DC grid voltage equals 20 volts. Using the programmed droop characteristic, the power congestion management should correct automatically.

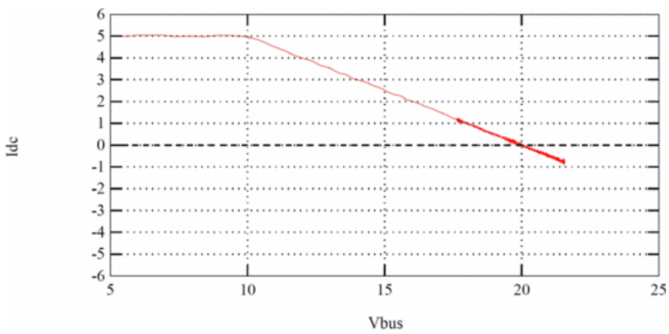

Fig. 9. Droop control characteristic.

Fig. 10. Gridmanager.

By setting the voltage on the main cable with an external power supply (performed by the laboratory supervisor), different scenarios can be tested.

Using this approach, the laboratory exercises vary from simple entry-level assignments to more advanced assignments. There is also room for going into detail for the advanced students, by explaining the functioning and operating principle of the used power converters.

The experimental setup is working at a low voltage, so everything is safe and the students can measure everything using a probe and safely touch all terminals.

Students can adjust the set points themselves, and immediately measure the response of such a setting. Using a multimeter and because of the low voltage, students can immediately safely measure voltage and current. The 10 red and 10 green LEDs (VU-meter) immediately display the influence of the setting, as these LEDs indicate the size and direction of the current. Figure 10 shows the Universal Four Leg as gridmanager and configured as a droop controller.

8 RESULTS AND REQUIREMENTS

For each objective, theory, simulation and experimental results have to meet the minimum requirements. For this, the students have to complete questionnaires on several subjects within each objective. For the questionnaire on the theoretical part in lecture 1, it is required to calculate a set of parameters, to be applied in the following lectures, in the simulation of the digital twin and the experimental setup. These parameters are checked by the lab instructor, and only after approval can the student continue with the simulation of the digital twin.

The simulation results have to be reported as wave-forms in a graphical plot. After a visual check by the lab instructor, the student is allowed to perform the laboratory experiment. The constant numerical results, like output voltage or load current, have to be presented in a table in the report. The wave-forms as measured on the oscilloscope in the experimental setup, have to be included in the report as screenshots.

The results from the simulation of the digital twin and the results from the experimental set-up, should be comparable within a certain region. A deviation of up to 5 to 10% is allowable, and the experimental results will show much more high-frequency effects. If the results are comparable, the student will get a mark that they finished that typical objective. The student needs to finish each objective, before continuing to the next objective. These short moments of checking values achieve more students to understand every step in the process and help students not to continue with wrong values. This allows students not to deviate too far from realistic numbers and help them to get a better feeling for the subject. This translates to overall better grades for their exams in these topics and a higher success rate in finishing the lab courses.

9 CONCLUSION

To teach the subject of power congestion management in DC grids, requires a specific approach. Learning by doing is the first that comes into mind, but hands-on practical training is required to give the students the look and feel of the real appliances. The fact that the students are using real appliances, gives them the confidence that the approach contributes to an understanding of the subject in detail.

To get to this understanding, the students first have to pass the theoretical part, and via simulation studies, they are prepared for the real experimental set-up. The fact that a digital twin is used in the simulation, gives them better insight on what is possible with the real experimental set-up.

Using three methods, theoretical evaluation using calculation tools, simulation of the digital twin and finally the experimental set-up, the students are working on four learning objectives. These learning objectives are to be carried out in the proposed order.

An optional assignment combines the learning objectives from the third and fourth week. For this students have to work in groups and connect their laboratory setups.

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PODCASTS AS A LEARNING METHOD IN ENGINEERING EDUCATION

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ABSTRACT

Multimedia has been integrated in education the last 40 years but podcasts have more recently become popular. Since 2006 podcasts have become increasingly popular in Sweden and nowadays podcasts are used in all types of contexts but are yet to find a place in engineering education. Students do not acquire knowledge or solve problems in the same way. Using a mix of methods in teaching is therefore important if one has the ambition to democratize the learning processes and give students the same opportunity to learn. Traditionally, much of the university education has been based on lectures in classrooms and reading literature. During the pandemic, teachers switched to video lectures and online lectures. Even though all types of multimedia are involved in teaching today, podcasts have not become established as a learning method. This paper explores in what ways podcasts can be beneficial in engineering education. Specifically, the paper investigates what preferences students have on how podcasts for engineering education and how teachers effectively can design and develop podcasts in courses as a learning method. By addressing the gap of evidence on podcasts in engineering education, the findings contribute with effective solutions on how podcasts can be developed and implemented that will help students in their learning processes.

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1 INTRODUCTION

1.1 Podcasts in Education

Traditionally, much of the university education has been based on lectures in classrooms and students' own reading of literature. In our digitalized society it is natural to promote education based on digital technologies. Podcasts is an emerging digital communications medium that is frequently used but has not yet found a place in engineering education. The podcast format brings together the student and the teacher (user vs creator/podcasters) in a specific content and context. One of the strengths of the medium is its intimacy: the student and the teacher are in the same headphones. It builds credibility and trust, even when podcasts are playful, humorous and taking turns.

Today, half of all Swedes listen to podcasts every week. Among young people, it is 65%. And the demand for new stories, developed reasoning and stories aimed at specific target groups is constantly increasing. Many talks about an "audio revolution", both in terms of listening, but also the emergence of a completely new industry for those who want to become podcast producers, screenwriters, or content creators for podcasts. The podcast format facilitates the teacher to share knowledge in a certain topic as well as reasoning, analyzing, and explaining the subject. One of the main advantages is the flexibility and availability of podcasts. Students can listen to the material whenever they want and they can pause and rewind back for review [1]. These advantages as well as the independence of the physical classroom make podcasts also beneficial for students with certain needs [2].

The aim of this study is to explore the potential of using podcasts in engineering education. The research question for this study was *How can podcasts be effectively designed and developed for university students, in particular engineering students?* The paper is based on a quantitative survey that combines several perspectives of students' preferences for podcasts in education. Several previous studies have investigated podcasts and their positive impact on student learning [3] and why students use podcasts and how satisfied they are with them [4]. Surprisingly, few studies have investigated students' preferences and attitudes for podcasts. Thus, this paper explores the student perspective and what preferences and attitudes they have for podcasts.

1.2 Blended Learning

Students do not acquire knowledge or solve problems in the same way. It is something that was shown, for example, by the research done by Kolb [5]. Using a mix of methods in teaching is therefore important [6], [7], [8], if one has an ambition to democratize the learning processes and give all students the opportunity to learn. The term “blended learning” can describe the approach when several forms for learning are used and combined [9], [10], [11]. The combination of traditional face-to-face learning and e-learning can be seen as a central aspect of blended learning [12].

Podcasts can pedagogically facilitate students to have control of their learning and study at their own tempo with differentiation in learning [13]. From this perspective, podcasts can facilitate the so-called “flipped classroom” approach [14]. The approach is that traditional lectures are available for students when they want and the teacher-led activities are more focused on explanations and theoretical based discussions. For example, podcasts can hypothetically be used as inspiration to a certain topic that the teacher will explain in depth in the classroom or podcasts can be used as a tool for repetition and/or summarizing topics. From this perspective, it is possible to assume that the teacher takes the role as a “coach” that guides the students in their learning process to achieve the learning outcomes [15].

2 METHODOLOGY

2.1 Sample and Data

Following a descriptive research design [16], [17], this study explores the potential of including podcasts in education based on existing literature and quantitative data. Data were collected between February 29 and April 30, 2023. The survey consisted of question about preferences for using podcasts in education. Data comprised a representative sample of engineering students at Linköping University. In total, 40 responses were usable and complete. To assure a diversified sample, students in different courses were included. The selection of students was done based on the courses that we currently are teaching. Examples of courses were: (1) InGenious (2) Innovative entrepreneurship (3) Entrepreneurship and idea growth. Students participated in the study on a voluntary basis.

The data were collected by the authors, using a questionnaire conducted in English. The data collection procedure was carried out by means of an invitation to take part in a digital survey, sent by a text message at the course website to the students. Participation was voluntary, and we assured the participants that their anonymity would be protected. The option to respond via a smartphone or tablet was offered at the webpage. To increase the response rate, respondents were offered a long response period.

2.2 Measurement

The background questions in the survey were chosen to provide a basic understanding of the students’ demography including the following questions: age, gender and previous studies at university level. Then students were asked about their previous experiences of podcasts as well as what preferences they had for podcasts in the future. Their future preferences of podcasts e.g., format, length were explored. The operationalization is consistent with other studies that have investigated students' preferences for podcasts in the educational settings, see [4], [18].

This article focuses on the development of podcasts for university students, in particular engineering students, and their preferences for podcasts but also how teachers effectively can design and develop podcasts. Therefore, the last part of the survey covered more specific questions about content and learning. This part of the survey was answered on a 5-point Likert scale, ranging from 1= ‘don’t agree at all’ to

5 ='completely agree'. For all such questions, respondents were also offered a 'don't know' option.

2.3 Methodological Considerations

The problem of "social desirability" [24] is when respondents might answer the questions in the way that puts them in a good position. Thus, it can potentially have an impact on the data. However, this is not a crucial problem in this paper as the introduction of the survey stated that all answers were treated coincidentally with anonymity and that the results were treated in aggregate form. Thus, no answers from a certain individual and their preferences could be identified.

The data collected and the measures developed should represent a trustworthy description of the phenomena, both from a reliability and validity perspective [25]. Podcasting preferences of students is a social phenomenon, and it is difficult to develop a general understanding without considering the context.

3 RESULTS AND DISCUSSION

Descriptive statistics are presented of the podcasts preferences in Table 1. In total, 40 students were included in the study (29 men, 10 women, 1 non-binary). The average age of students was 24 years. The majority of students (31 students) had previously studied, 4-5 years was the most answered category. In general, most of the students (31 students) currently listen to podcasts three times per week or twice a week (7 students), one time per week (1 student) and currently do not listen to podcasts (1 student).

Table 1. Results from the survey

Questions	**Number of students** N = 40	**Share of all students** 100%
Today, I listen to podcasts which length is…		
-10-20 minutes	2	5 %
-20-30 minutes	3	7.5 %
-30-40 minutes	4	10 %
-40-50 minutes	9	22,5
-50-60 minutes	7	17.5 %
-60 minutes or more	6	15 %
-Do not know/do not listen	9	22.5 %
The optimal length of podcasts in education would be…		
-10-20 minutes	6	15 %
-20-30 minutes	18	45 %
-30-40 minutes	10	25 %
-40-50 minutes	2	5 %
-50-60 minutes	2	5 %
-60 minutes or more	1	2.5 %
-Do not know	1	2.5 %

Podcasts for education should be… -Humorous -Entertaining -Inspiring -Informative -Contain guest -Contain famous people -Give new knowledge -Interesting -Other	 15 15 4 4 0 0 0 1 1	 37.5 % 37.5 % 10 % 10 % 0 % 0 % 0 % 2.5 % 2.5 %
I like to listen to podcasts… -Before a course begins -At the end of each week as repetition -Before the exam -Spontaneously during the course - Other	 7 7 5 16 5	 17.5 % 17.5 % 12.5 % 40 % 12.5 %
How much of the course' teacher activities would you like to have in podcast form… -A smaller part -Half -A larger part -All the lectures -Other	 18 11 4 3 4	 45 % 27.5 % 10 % 7.5 % 10 %
Preferences for podcasts in a university course -I would like to have a model/theory explained in a podcast -I would like to hear the teacher reason and analyze a topic in relation to real-life examples -I would like to hear a lecture in a podcast -I would like the course literature to be read aloud in a podcast -I would more easily get a pass/higher grade in the course if I had access to a podcast -I would remember the content better in a course if a podcast was available in the course -A podcast would supplement the course literature with new perspectives -I would more easily get a pass or higher grade in the course if I had access to a podcast	 3.9 4.4 2.8 2.6 2.7 2.9 4.0 2.6	

4 DISCUSSION AND CONCLUSIONS

The aim of this study was to explore the potential of using podcasts in engineering education. We found that the majority of students today listen to podcasts that are 40-

50 minutes long. However, they prefer a shorter length of podcasts that are intended for education, 20-30 minutes. Contrary to expectations, students prefer rather long podcasts compared to previous studies that claim that podcasts should be “short” 1-5 minutes [19], or 18 minutes [20]. We believe that students within 20-30 minutes can gain a basic understanding of the subject on their own and then develop their skills and abilities together in the classroom.

Students had the strongest preferences for humorous and entertaining podcasts (15 students per category), compared to the categories inspiring and informative (4 students per category). There is a basic assumption that podcasts should be informative [19], but this result clearly shows that students want humorous and entertaining podcasts. Another finding is that students prefer to listen to podcasts spontaneously during a course (16 students) and would like to have a smaller part of the course teacher activities (18 students) or half (11 students) in the podcast format. This result confirms previous research which claims that podcasts can complement traditional teaching i.e. lecturing being a complement for students [21]. Building on [22] (cited in [23] p.3), we thus argue that the traditional classroom teaching can be added with the podcast component resulting in a blended learning environment that is beneficial for students.

Figure 1. Blended learning environment based on podcasts

We also specifically asked students about their preferences for content in podcasts. In line with previous research, students rated the question “I would like to hear the teacher's reason and analyze a topic in relation to real-life examples” relatively high, (4.4 on a 5-point scale). The question “I would like to have a model/theory explained in a podcast” is also relatively high (3.9). In line with expectations, the questions “I would like to hear a lecture in a podcast” (2.8) and “I would like the course literature to be read aloud in a podcast” (2.6), are relatively low numbers. On the question “A podcast would supplement the course literature with new perspectives” students answered relatively high (4.0). This shows that students rather want the teacher to inspire, reason and explain specific content in depth. In line with the reasoning on podcasts as a complement to traditional teaching, students answered only (2.9) on “I would remember the content better in a course if a podcast” and (2.7) on “I would more easily get a pass/higher grade in the course if I had access to a podcast”. Finally, the result (2.6) on the question “I would more easily get a pass or higher grade in the course if I had access to a podcast” also confirms this. Overall, students think that podcasts have the potential to be an important complement to the existing teaching and can help in the learning process, but it does not help them to receive a higher grade or easily pass the course.

5 CONCLUSION AND RECOMMENDATIONS

The aim of this study was to explore the potential of using podcasts in engineering education. There is no question that the podcast format is a valuable pedagogical tool. However, the design, format and content of podcasts are very important. Hence, the recommendations for teachers to effectively design and develop podcasts in courses, are to keep podcasts short, approximately 20-30 minutes and focus on the reasoning and analyzing (a certain topic, model or theory in relation to real-life examples). The podcast should be available for spontaneous listening during a course and should not replace ordinary teaching activities. They are recommended to be seen as a humorous and entertaining element that can supplement the course with new perspectives. The fact that students seem to prefer humoristic podcasts could be seen as a drawback from an academic perspective. However, it could also be seen as an opportunity to package theories and models in a more prestige less way and through this make them easier to access.

Finally, working with podcasts as a tool for teaching comes with learning thresholds. According to our own experience, the best way to overcome this is to start on a small scale and make shorter presentations as a complement. The equipment needed to produce a podcast is rather simple, basically it is a quiet room, software, mics and a small mixer. The sound quality is rather important though, so to start, the best way probably is to use an existing studio, and these have become rather common at most universities.

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EXPLORING THE FABRICATION LAB CONCEPT FOR LEARNING SUSTAINABLE CO-INNOVATION IN INDUSTRIAL ENGINEERING EDUCATION – AN ACTION RESEARCH CASE FROM AUSTRIA

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Keywords: *engineering education, fabrication lab, co-innovation, sustainability*

ABSTRACT

According to recent studies, cooperative innovation between universities and industry, especially with small and medium firms, is not as frequent as expected. Case-studies of regional innovation systems have shown that open access to state-of-the-art research infrastructure, services, skills and activities are needed to achieve long-term innovation partnerships. Co-innovation requires particular skills beyond technical knowledge, which are not always addressed in engineering curricula at university. Fab labs are a concept that potentially fosters students in the acquisition of such skills. In this paper, we describe our experiences in designing, building and running a fab lab as a new element for industrial engineering education at our university in Austria.

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1 INTRODUCTION

Regional innovation systems (RIS) can be understood as "a set of interacting private and public interests, formal institutions and other organizations that function according to organizational and institutional arrangements and relationships conducive to the generation, use and dissemination of knowledge" (Doloreux 2003). The basic idea is that different stakeholders with academic, entrepreneurial and governmental background and motivation are the foundation that encourages a region to develop innovative capability and competitiveness (Gertler 2010).

Based on a multiple case-study, the European University Association (EUA) recently reported that universities and companies are changing from linear innovation models to co-creative, systemic approaches with external partners (EUA 2019). Their report outlines major determinants of these new forms of cooperation observed at European universities and their partners in regional innovation systems. Among other determinants, case-studies have shown that access to expensive large state-of-the-art infrastructure and technical facilities as well as equipment with technical support staff and joint institutes or labs are needed together with joint research activities on all levels, reaching from student thesis projects to joint product development, in order to achieve long-term research partnerships.

Moreover, co-innovation with enterprises is not self-perpetuating, as it requires particular skills beyond technical knowledge. Research shows an increasing need for sustainable innovation competences among engineers, such as creativity, problem-based thinking and a sense of responsibility, which inevitably influence teaching concepts and goals in engineering education (Piippola et al. 2012). According to different studies in engineering education research, however, engineering curricula often fail at addressing such competencies, thus mainly focusing on narrow technical specifications (Cropley 2015) and ranking a broad theoretical knowledge as a foundation for getting involved in further engineering courses (Dym et al. 2005).

In this paper, we describe our findings from a recent case in Austria, where we have explored the concept of fabrication labs as an approach to provide ongoing engineers with innovation competencies during their studies, thus promoting sustainable innovation with other stakeholders in the regional innovation system in Austria. In the next sections, we describe in short the basic theoretical background of our approach, the methodological approach and the main findings and impact we experienced on industrial engineering education.

2 BACKGROUND

2.1 Challenge-Driven Education and skills for sustainability

In their study, the EUA (2019) identifies a change in the innovation approach of stakeholders in the innovation system, thus shifting from technological to challenge-driven innovation. This often takes place in common spaces with an increased focus on sustainability and can be also reflected by educational approaches at university, e.g. by Challenge-Driven Education (CDE). The latter not only aims at developing solutions that are sustainable under an environmental, societal and economic point of view (e.g. Rosén et al. 2018), but also allows students to approach societal challenges in all its complexity. Malmqvist, Kohn Rådberg, and Lundqvist (2015) highlight how this feature of CDE uniquely allows students to train important additional skills, reaching from teamwork to addressing societal issues. Working on real, interdisciplinary challenges in cooperation with actors outside university, moreover, provides students with professional skills for their future career (Klaassen et al. 2022).

In general, the underlying approach of teaching students in a cooperative context with companies also contributes to UNESCO's Sustainable Development Goals (SDGs) (UNESCO 2015) in multiple ways. For example, CDE allows ongoing engineers to actively practice inclusive innovation at a regional level, thus supporting SDGs n. 8 and 9. Student cooperation with other stakeholders in the innovation system contributes to SDG n. 17 and allows to address challenges that are shared by different actors in society. Sharing knowledge across disciplines to develop sustainable solutions supports responsible consumption and production (SDG n. 12).

2.2 Fabrication lab concept

The concept of fabrication labs (fab labs) basically refers to workshops that offer open access to low-level manufacturing and prototyping equipment (Gershenfeld 2012). The basic idea is to open up access to often expensive manufacturing technologies, therefore supporting bottom-up innovation. Meanwhile, fab labs have spread around the world and are recognized as potential innovation facilitators (Cattabriga 2020). The Interreg initiative of the EU (2022) highlights different case studies showing that fab labs are a suitable instrument to promote university-industry collaboration and support regional innovators, also fostering prototyping, knowledge sharing and the training of new skills.

3 APPROACH

Our university is located in a relatively small city in Austria with a high density of industrial firms. The regional government strives to encourage innovation activities and cooperation between different stakeholders. As part of this effort, infrastructure for joint research and development has been publicly funded. Therefore and because of the advantages mentioned by Gershenfeld (2012), we decided to establish a fabrication lab at our university.

In this paper, we will describe our experiences from conceptualizing, building and running an open fab lab at our university with regard to enhancing engineering education. The whole project was pursued in a way that can best be described as an action research approach. Action research as proposed by Gustavsen (2005) aims at getting involved in a (social) situation, understanding it, improving it and creating knowledge from shared experiences made during the process of improvement. While conceptualizing, building and running the fab lab, we conducted different steps in an iterative manner, flipping constantly between a more observing position to understand the situation, problem and effects of measures and a more intervening position, where we developed and implemented measures. For example, in order to identify expectations and needs of the different stakeholders involved, we organized meetings and conducted surveys both with students and other potential user groups throughout the project. All feedback and results from discussions and surveys were documented and analyzed (see Erol and Klug 2020, Böhm et al. 2022).

The project plan was set up to achieve three main goals, (1) the setup of the whole fab lab infrastructure (see Fig. 1) including the building, work places, machines, amenities, (2) the development of service offerings and processes to support co-innovation activities and especially educational activities in co-innovation and (3) the growth of a community of corporate and university users. Given the main goals, the corresponding work packages have been conducted partly in parallel, which allowed us to shorten the overall project time and to constantly adjust infrastructure to service needs and vice versa. Also reach-out activities to corporate users, faculty and students started in an early phase, e.g. engineering students have not only be involved through feedback cycles but also as part of the team that designed, built and run the lab, corporates have been invited and shown around during build phase.

Fig. 1. Newly-built fabrication lab located in a former factory building (Sept 2021)

4 RESULTS

Results of the project have been grouped according to their type of impact. Accordingly, we describe experiences and lessons learned from designing, building and running the fab lab during the period from Jan 2021 to Jan 2023 (19 months, overlapping design phase: 6 months, build phase: 6 months, run phase: 16 months).

4.1 Impact on regional innovation infrastructure

The fab lab was built on around 1,100 sqm in a former factory building near to our university campus and in the center of an industrial area. It consists of 7 sub labs, each focusing on a specific technical area of expertise. In particular, these are: (1) Metal Lab, (2) Wood Lab, (3) 3D Printing Lab, (4) Electronics Lab, (5) Textile Lab, (6) Laser Lab and (7) Robotics Lab. All these sub labs have workplaces equipped with a computer and domain specific software to support digital workflows from modeling and simulation to manufacturing of prototypes.
The actual status of service offerings developed can be seen in Table 1. Services are targeted at different user groups identified, e.g. corporate users as industrial enterprises, start-ups and research institutions, private users and students. A distinction is also made between services for expert users and novices needing extra support, e.g. a basic technical training on a particular machine or manufacturing technology. Although they are tailored to specific user groups, most of these services are open to all users, thus enabling encounters and exchange between students and other user groups as well. Service offerings were developed based on qualitative interviews and a review of service offerings from similar fab labs. Results were subsequently validated, adapted and extended to suit specific needs of the user groups. For this purpose, discussions in the core team, interviews with students and other potential user groups were conducted.

Table 1. Implemented service offerings in the lab (by Jan 31st, 2023)

Service offering	Description	Staff involvement	Target group
Self-service for machinery and equipment	*Users use machinery and equipment on their own 24/7*	*Self-service*	*All target groups*
Managed project space	*Users use blank space for large projects and may use machinery and equipment*	*Self-service*	*Industrial enterprises, start-ups, research institutions*
Basic technology trainings	*Trainings to learn machinery and equipment in the lab*	*Internal staff*	*All*
Advanced technology trainings	*Trainings to learn advanced techniques to create prototypes and products in the lab*	*Internal staff and external partners*	*All*
Innovation workshops	*Workshops to learn new methods and techniques in product development*	*University staff and external partners*	*Industrial enterprises, start-ups, research institutions*
Community meetings	*Informal get-together for news and idea exchange, networking*	*Internal staff*	*Students, private persons*
Competitions	*Organized idea challenges, e.g. hackathons, challenges*	*Internal staff, university staff and external partners*	*Students, industrial enterprises and services, start-ups*
Conferences	*Organized special topic conferences with interactive parts*	*Internal staff, university staff and external partners*	*Students, industrial enterprises, start-ups, research institutions*
Corporate presence	*Enterprises of every size can present themselves in the context of the lab*	*Internal staff*	*Industrial enterprises, start-ups*

4.2 Impact on cooperation with regional industry and community

Reach-out activities carried out from the very beginning of the project supported us in introducing the new infrastructure and service offerings among stakeholders in the region. In order to foster co-innovation, we organized several networking events, e.g. a conference (Inventors Day) dedicated to address inventors in the region and connect them with industrial enterprises, founders, investors and students. Another event (Circular Design Day) brought together pioneering companies and students in the field of circular design. We also organized hackathons and challenges and invited companies to pose challenges and students to jointly develop ideas and solutions. Here, we experienced a strong interest from industry to meet talents of the future. However, due to a rather large amount of such events, students need to see a particular benefit to be willing to participate.

To date, the fab lab has also hosted three large-scale publicly-funded innovation (R&D) projects with regional industry in automotive, aircraft and furniture manufacturing sectors. These projects used both equipment and project space for a limited time. Other small-scale development projects have been conducted in cooperation with local companies, e.g. the development of 3D-printed furniture feet. Students are involved in these projects, e.g. they developed an iron bird mock-up for a new electrical transport drone as part of a larger research project.

Since the beginning of 2023, 24 regional companies and institutions fund the lab. 9 companies actively use the lab, under which 3 are start-ups, one is an individual company and 5 are large enterprises, as well as 2 private research institutions. 4 of the companies are users and sponsors at the same time. Companies mainly perform development and prototyping activities and want to attract personnel and potential partners for R&D. A regional high school uses the lab to hold workshop classes, 42 private users have joined the lab and use it on a regular basis for private projects, 56 faculty members have registered to use the lab for teaching their courses (or parts of) in the lab and 117 students from our university have joined as they do or plan to accomplish student projects, bachelor or master theses (see Fig. 2).
The fab lab is now an established regional innovation infrastructure and is listed in the registry of significant Austrian R&D infrastructures.

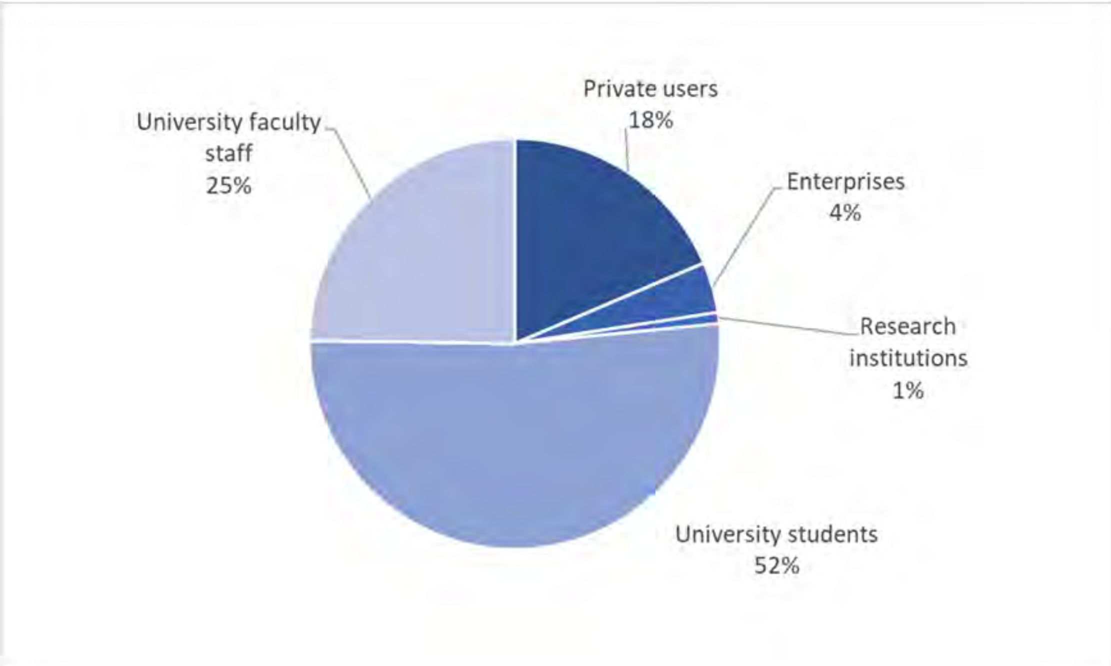

Fig. 2. Community (user groups) of the fab lab, n=226 (by Apr 30th, 2023)

4.3 Impact on engineering education

From the very beginning, we involved students of industrial engineering programs. Two industrial engineering students were employed part-time and became part of the core project team. We also created a volunteer scheme and invited students from the engineering faculty to participate in the project. From an initial group of around 20 volunteers, around 10 students remained and supported us to build and start up the fab lab. We held monthly meetings to inform them about the progress, collect feedback and distribute tasks. Students' technical background was diverse and considered in distribution of tasks. After opening the fab lab, four volunteer students were employed permanently to support us in user management, maintenance and trainings. We learned that students with a strong background (educational or autodidactic) in making or manufacturing preferably joined us. Those students that remained in the long term were students that used the fab lab for their own projects at university or privately. A short geographic distance between home and university campus was another reason that favored student participation. Some students quitted the initial team due to time

constraints because of commuting or additional jobs. The fab lab became a meeting place for students. Especially when they worked on projects, we observed vivid knowledge exchange across students from different engineering programs, e.g. mechatronic students helped industrial engineering students in bug fixing at a 3D printer controller unit. Three of our student team members completed their thesis about particular problems and respective solutions they developed in the fab lab, e.g. the efficient scheduling and automation of print jobs in the 3D printing lab.
After opening up the fab lab (Sept 2021), lecturers were invited to use it in courses and also invite their students to use it for bachelor and master thesis projects. The fab lab's unrestricted opening times (24/7) proved to be useful, as students were not bound to the presence of a lecturer and limited opening hours to complete their projects. However, after a first rather uncontrolled run on the lab, we had to introduce a workflow that ensured that students got authorization form their study program head and had to pass a basic technical and safety training before getting open access. The basic technical and safety trainings are open to all user groups. Given that, students get in contact with professionals and corporates and are able to learn from each other.

Fig. 3. Students working on rocket launch system (3rd semester)

Fig. 4. Students working on a mobile barbecue (4th semester)

Today, students of the industrial engineering study program use the lab in different ways. In the first semester, in the course of a lecture on manufacturing technology, they get a practical training on different manufacturing technologies in the fab lab. The training follows a CDE approach in which students need to manufacture a given product, e.g. a home tool box, that involves different machines, equipment, materials and therefore are able to apply theoretical knowledge to a real world problem. In the fourth semester, they are able to use the fab lab in the course of a lecture on product development and engineering (see Fig. 3 and 4). They are encouraged to develop a prototype product for a given problem area, e.g. a mobile barbecue. Later on in their studies, they learn how to use design thinking methods for early prototyping in the fab lab. Many students subsequently use the lab for their bachelor and master thesis projects when developing prototypes, e.g. a student developed a pair of remotely coupled mobile robots. Similar developments can be observed in other study engineering programs.

5 CONCLUSION

In summary, the establishment of a fab lab at our university has proven to significantly contribute to university-industry cooperation in regional innovation. Due to the early involvement of industry partners and students, the fab lab is now a platform where industrial firms can meet and work together with engineering students. Different activities during the last 16 months of operation have led to intensifying and expanding exchange and collaborations between the two spheres of practice and academia. The open workshop environment in the fab lab encourages informal exchange and eases access to technical equipment, both for industrial research and development and practical engineering education in the region.

Major learnings are that (1) early involvement of industry, students, study program managers and research-focused institutes is vital to develop adequate service offerings, (2) regular social events and outreach are necessary to develop a critical mass of users, and (3) inclusion of the fab lab in curricula must be given, ideally in early semesters, to make students familiar with it and therefore lower barriers for using it. The latter learning was not addressed properly at the beginning of the project, especially as curricular changes take quite a long time and internal procedures to take effect. In the future, we plan to develop metrics to quantitatively measure the impact of the fab lab on engineering education. We plan to measure both the perceived impact in the short term and the impact on innovative activity in the long term.

Given very positive experiences in the industrial engineering study programs, we plan to intensify and encourage the use of the fab lab as a collaboration and education platform for further study programs at our university. Our service offerings will also be further expanded, as we work on introducing remote support via app until the end of the year.

6 ACKNOWLEDGEMENTS

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PROFESSIONALISING SCIENCE AND ENGINEERING TEACHERS IN GUIDING AND ASSESSING REFLECTION

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ABSTRACT

The current knowledge society of the 21st century requires students, among other things, to have the ability to think reflectively. Various studies show however that educational programs and teachers, from engineering programs in particular, experience difficulties in integrating the development of students' reflection skills in their curricula. This gave rise to a multi-year project on improving reflection in engineering educational programs. We worked with teacher teams of 6 programs to improve their curricula and teacher practices regarding reflection. Part of the project were training sessions for teachers focused on guiding and assessing reflection activities of their students.

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This paper presents a study that was conducted in relation to this training to gain insight into: 1) teachers’ guidance and assessment skills and 2) the contribution of the training to any changes in these skills. A selection of teachers of the participating teams were interviewed before and after the training (N = 8). To gain insight into teachers’ guiding skills, we designed and recorded video’s that depict multiple authentic, prototypical situations. Text excerpts of written reflection reports were used to unravel teachers thoughts and approaches regarding assessing students’ reflections. The interview protocol aimed to elicit teaching interventions and actions regarding guidance and assessment of students’ reflections and teachers rationales and thoughts behind these interventions and actions. Results indicate a shift in teachers’ guiding and assessment skills before and after the training; their skill repertoire seems expanded and reflection questions they would ask their students aimed at deeper reflection.

1 INTRODUCTION

1.1 Background

Within the current labor market there is a growing need for technically trained professionals. To function well within this labor market, young professionals should be able to critically react to often fast changing (knowledge) developments (World Economic Forum 2023). More specifically, there is an ongoing demand for technically trained students who are capable of reflective thinking in addition to their domain-specific specialism. Many authors state that reflecting is a basic skill for (future) professionals and therefore for students (Ryan 2013; van Beveren et al. 2018). Reflection is seen as a process of systematic thinking, in which one gains insights based on experiences, looks ahead and gains new experiences, with the aim of developing oneselves (professionally) (van Beveren et al. 2018; Meijers and Mittendorff 2017).

Though reflection as a means to foster students’ personal and professional development and the importance of incorporating it as essential part of the curriculum is generally acknowledged (Ryan 2013), schools and teachers experience difficulties regarding effective implementation of reflection in their programs (Hughes et al. 2017). Also, related research has shown that especially technical students not always recognize the added value of reflection and the written format that is often used to incorporate reflection does not fit this technical target group (Mittendorff and Pullen 2019). Teachers of several technical study programs in higher education have indicated that they have little knowledge and skills when it comes to these topics and express a need for further professional development (Mittendorff and Pullen in press).

The project Strengthening reflection in technical higher education programs'addresses these issues. In this project, efforts are made, among other things, to professionalize higher education science and engineering teachers in guiding students in developing their reflection skills and assessing students’ reflection activities. Guiding and assessing reflection activities of students appear to be two relevant topics for professionalization. In this paper addresses the way teachers perceive their own skills in relation to these topics and presents a study in which these perceptions were studied before and after training sessions on guiding and assessing students’ reflection activities.

1.2 Guiding and assessing reflection

Teachers play a crucial role in guiding students in their learning process and the development of skills such as reflection. For example, in teaching students *how* to reflect by jointly discussing a reflection process, or in guiding a reflective dialogue among students who are collaborating during a project In their role as coaches, teachers are primarily facilitating, activating, diagnosing, challenging and evaluating (Korthagen and Nuijten 2023). Coaching skills that serve as a starting point can be categorized into four categories (Mittendorff and Visscher-Voerman 2019):

- Creating a safe learning environment (atmosphere);
- Asking questions (goal: critical inquiry and reflection so that student is prompted to think);
- Providing feedback;
- Providing (targeted) support.

When it comes to assessing reflection, it is important to understand what reflection actually is, in order to determine the quality of specific reflection processes or activities of students. A reflection process starts with describing a meaningful situation, that an individual examines from both inside and outside. It continues withformulating insights based on that analysis and determining follow-up steps (see Fig. 1; Mittendorff 2014).

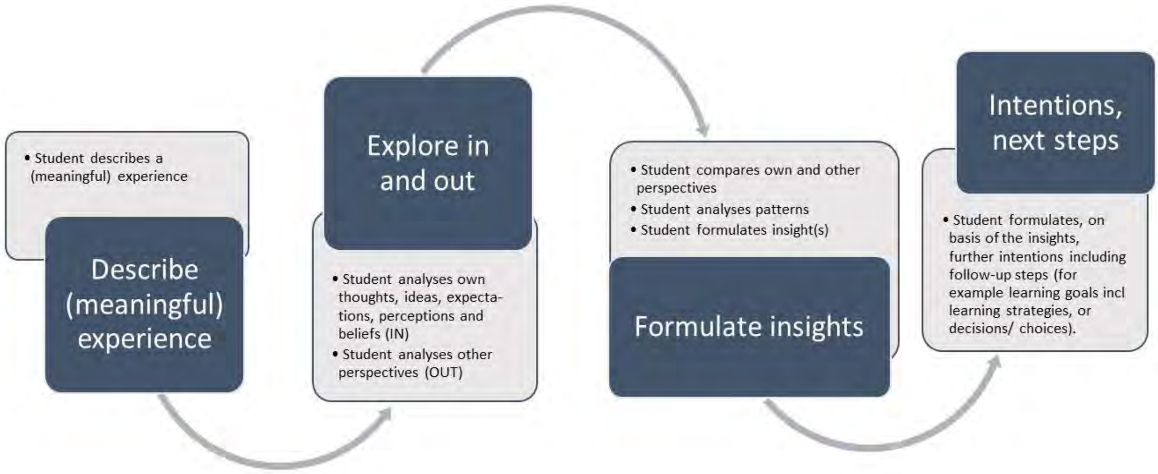

Fig. 1. Reflection Process

Reflection is different from evaluation, because it addresses what is 'under water' instead of merely at 'the surface'; it is aimed at discovering patterns and incorporating perspectives from both inside (e.g., your own thoughts, feelings) and outside (e.g., theory or knowledge, feedback of others) (Kember et al. 2008; Kinkhorst 2010).

When it comes to valuing or assessing students' reflection activities by teachers, it is important to take into account whether the different aspects or phases of reflection are present: are experiences described, are these experiences analysed (inside and outside), are insights summarized or formulated, and did one look forward to future intentions or actions? (Engelbertink et al. 2021). In addition, it is important to consider whether the various elements of a reflection process are connected or aligned.

This paper presents a study that was conducted in relation to training sessions for science and engineering teachers focusing on guiding and assessing students' reflection activities. It addresses the following research questions:

1) What do science and engineering teachers consider important in guiding and assessing students' reflections, and can we identify differences before and after the training?
2) Can we identify differences in teachers' (perceived) ability in guiding and assessing students' reflection activities, before and after the training?
3) Which elements of the training, according to the teachers, contributed to any increase in (perceived) ability in guiding and assessing students' reflection activities?

2 METHODOLOGY

2.1 Instruments

Interviews

To answer the research questions, a structured interview with science and engineering teachers was conducted both before and after the training (i.e., two weeks before the first and two weeks after the final training). To measure teachers' (perceived) ability, we took a twofold approach: 1) we asked teachers about their perceived ability, and 2) we elicited their reactions to videorecordings of situations in which students reflect and to student reflection reports. The pre- and post-interviews were similar in structure and content (see Table 1).

Table 1. Interview outline

<table>
<tr><td colspan="2">A. Important elements in guiding and assessing students' reflection activities</td></tr>
<tr><td colspan="2">What elements do you consider important when guiding and assessing students' reflection activities?</td></tr>
<tr><td colspan="2">B. (Perceived) ability in guiding students' reflection activities</td></tr>
<tr><td>Perceived ability
How skilled do you feel regarding guiding students' reflection activities?</td><td>Reaction to video recording (4x)
How would you react to this situation?
Can you give specific examples of what you would do, and why?</td></tr>
<tr><td colspan="2">C. (Perceived) ability in assessing students' reflection activities</td></tr>
<tr><td>Perceived ability
How skilled do you feel regarding assessing students' reflection activities?</td><td>Reaction to reflection report (2x)
How would you characterize the quality of this excerpt, and why?
What feedback would you provide to the student?</td></tr>
<tr><td colspan="2">D. Contribution of training elements (post-interview only)</td></tr>
<tr><td colspan="2">To what extent do you notice differences in the way you guide and/or assess students' reflection activities?
Which training elements may have contributed to this difference?</td></tr>
</table>

Video vignettes and reflection reports

Video vignettes

To elicit teachers' reactions in real situations, we designed and recorded four videos that represent authentic situations in which teachers guide students' reflections. The video recordings focused on prototypical situations an engeering context and commonly occurring 'issues' regarding students' reflections (for example: a conversation between a project supervisor and a group of students, during which the students reflect on their collaboration; students do not comply with their agreements and hardly communicate about this). To develop the videos the following procedure was followed: 1) based on literature, a selection of prototypical situations and commonly occurring 'issues' was made; 2) engineering teachers were consulted to finetune this selection; 3) based on step 1 and 2 a first draft of the scripts was designed; 4) engineering students were consulted fo finalize the scripts; 5) based on the final scripts, the videos were recorded with the same students.

Each video had a length of approximately 2 minutes and started with a sort description of the situation. The video's were played one-by-one during the interview.

Reflection reports

To gain insight into how teachers would assess students' reflections, examples of real reflection reports were requested from engineering teachers. From these reports, a selection of two text excerpts was made and anonymized.

2.2 Participants

Participants came from three study programs (Building & Infrastructure, Information Technology/Electrical Engineering, and Fashion Textile & Technology) of two universities of applied sciences in the Netherlands. The team lead of each participating teacher team was instructed to select 4 teachers (based on their availability and their intention to participate in the training) to be interviewed, teachers were then asked to participate in the interview, and all teachers were willing to do so. Initially, 11 teachers participated in the pre-training interview. Three of them were absent during more than one (out of three) training sessions and therefore not interviewed after the training. The remaining 8 teachers (6 males, 2 females), who were all interviewed before and after the training, were used as respondents in the analysis. All teachers were experienced in guiding and assessing students' reflections. The level of experience and the role(s) they have (e.g., study coach, project supervisor) varied.

2.3 Training

The training was developed and provided to the whole teacher team of the participating study programs. The training consisted of three sessions on the following topics: 1) guiding reflection activities of individual students; 2) guiding reflection activities of a group of students; 3) assessing/ valuing students' reflection activities. Each training session included a mix of information, hands-on activities and concrete tools to support teachers in guiding and assessing students' reflection activities. The sessions took about three hours each.

2.4 Data-analysis

All interviews were recorded and transcribed. A within-case analysis was performed to create an overview of answers to the interview questions per teacher. Therefore, transcripts of each interview question were summarized per case. To gain insight into which guidance strategies teachers would employ and how they would approach assessment of students' reflections, their reactions to the video recordings and reflection reports were categorized by adopting a deductive coding approach. Teachers' reactions to the video recordings were coded as one or more sub-categories as presented in Table 1. Regarding teachers' reactions to the reflection reports, it was determined whether attention was paid to the different aspects or phases of reflection and their interconnectedness (Engelbertink et al. 2021).

The following procedure was adopted to categorize the reactions (which was done by two coders). First, a small selection of answers was discussed together. Second, both coders coded a selection of answers independently of each other and discussed differences and similarities of this selection afterwards. Third, descriptions of the codes were further refined based on the discussion. Fourth, the second and third step were repeated, afther which the full dataset was analyzed.

Finally, a cross-case analysis was conducted to gain insight into the similarities and differences accross the eight cases, both on the pre- and post interview.

Table 1. Overview of codes to characterize guiding behaviour, based on Mittendorff and Visscher-Voerman 2019

Codes	Sub-codes
Creating a safe learning environment	• Creating space for students to ask questions and/or share ideas • Demonstrating genuine interest (by demonstrating curiosity and/or by listening actively)
Asking questions	• Aimed to elicit evaluation • Aimed to elicit reflection • Directed to one or more reflection steps (and their interconnectedness)
Providing feedback	• Mirroring students' behaviour • Sharing opion about the situation • Providing a frame of reference for behaviour • Helping students to gain self-awareness
Offering (targeted) support	• Scaffolding by providing tailored help • Modeling behaviour

3 RESULTS

The results below present the main findings of the cross-case analysis for the pre- and post- interview in relation to the research questions.

3.1 Important elements in guiding and assessing students' reflection activities

Overall, answers among teachers differed, during both the pre- and post-interview.

<u>Guiding reflection activities</u>

During the pre-interview teachers noticed, for example, the importance that students *become aware* of their own behaviour and that they *look back* to see what could have been done differently. Regarding important guidance elements teachers mentioned, among other things, to *ask questions* instead of merely forwarding information to their students. An aspect mentioned more than once, is to allow students '*to think by themselves*'.

During the post-interview, teachers noticed aspects such as helping students to *recognize patterns* in their behaviour, trigger students to *increase awareness* regarding their behaviour, and having students *practice reflection* by means of a model. Similar to the pre-interview, the importance to allow students *'to think by themselves'* was mentioned more than once. What stands out is that five out of eight teachers during the post-interview noticed the importance of *facilitating a safe environment and stimulating mutual trust*, whereas this was not mentioned during the pre-interview.

<u>Assessing reflection activities</u>

During the pre-interview teachers mainly noticed the extent to which students provide *concrete descriptions* (e.g., whether they describe their role/contribution during a project, how the process evolved, or whether they provide concrete examples).

During the post-interview two elements stand out. First, teachers indicated the importance of *coherence during students' reflections* (i.e., whether they go through the full reflection process and whether there is a connection between the various steps; for example, a connection between insights regarding the current situation and future actions). Second, some teachers noticed the extent to which students provide an *in-depth reflection* (e.g., beyond merely an evaluation of the situation, willing to take into account their emotions, recognizing behavioural patters and deriving insights form these).

3.2 (Perceived) ability in guiding and assessing students' reflection activities

<u>Guiding reflection activities</u>

Perceived ability

During the pre-interview teaches indicated to feel rather skilled. Two of them indicated to act merely on intuition. Teachers' perceived ability during the post-interviews seems very similar to the pre-interview. However, two of them indicated to feel more skilled, whereas one teacher declared to feel somewhat less competent after the training, because of all the information provided and lessons learned.

Reactions on video recordings

The analysis of teachers' reactions and provided examples of what they would do in certain situations (as portrayed in the video recordings), showed that teachers demonstrate different guidance strategies when comparing their answers on the pre- and post-interviews. Although the answers between teachers differed, an obvious finding is that teachers demonstrate a more extensive skill repetoire during the post-interview compared to the pre-interview. The strategies described below became more often apparent in the post-interview, compared to the pre-interview.

The main difference was found in *providing feedback*; teachers showed or indicated to provide more feedback. More specifically, they would more often mirror students' behaviour and help them to gain self-awareness. Also, teachers were more concerned about *facilitating a safe environment* when guiding students' reflections. Their reactions were more often categorized as 'creating space for students to ask questions and/or share ideas' and 'demonstrating genuine interest' (for example by demonstrating curiosity and/or by listening actively). Finally, teachers would *ask questions* more often and provide more examples of questions they would ask. Also, these questions seem to aim for more in-depth reflection (i.e., more focused on feelings, underlying assumptions, understanding of patterns in students' behaviour, and future actions). For example, during the pre-interview a teacher would ask ‘what is going well?’ and ‘what can be improved?’, whereas during the post-interview, this teacher would ask more nuanced questions, such as ‘what makes you dislike this course?’, ‘what would you like to learn?’, ‘taking into account next academic year; what would make you happy?’, ‘what motivates you?’.

Assessing reflection activities

Perceived ability

During the pre-interview, half of the teachers indicated to feel rather skilled, whereas the other half indicated to feel not (very) skilled. During the post-interview half of the teachers pointed out to feel more skillful compared to how they felt before the training. Two teachers noticed to feel less skillful, because of the gained insights during the training. Others found it difficult to indicate how skillful they are.

Reactions to reflection reports

Considering how teachers would characterize the quality of students’ reflections and their reasoning behind it, teachers’ assessments during the pre- and post-interviews can be labelled rather similar. However, it is noteworthy that during the post-interviews, teachers more often payed attention to particular reflection steps; whether students would *look ahead* and provide *concrete future actions*. Also, teachers put more emphasis on whether students’ reflections are personal and whether students are making connections between reflection steps (e.g., whether they link the current to a previous situation in order to discover patterns).

3.3 Contribution of training elements

Although not all teachers specifically indicated whether the training contributed to their ability level, most teachers indicated that they have received concrete tools that would help them in guiding and assessing students’ reflection activities. Examples of tools that are found to be helpful are a provided reflection model (with reflection steps), reflection cards (with example reflection questions that teachers could ask to guide students’ reflections), and a reflection rubric (with an indication of various reflection levels). Teachers recognized the importance to practice their teaching skills regarding guiding and assessing reflection with the help of these tools. However, they also indicated that they would appreciate more time to practice these skills and to discuss examples of students’ reflections with colleagues.

3.4 Conclusions

The results showed that the science and engineering teachers that participated in this study differ in terms of how they perceive their own ability to guide and assess students’ reflection activities, both before and after training. This shows that, as with students, it is crucial to scaffold teachers’ learning (and their reflection) (Coulson and Harvey 2013). Overall, teachers do not explicitly express an increase in their guidance or assessing skills. However, when they are asked what they would actually do in real situations (as portrayed in the video recordings and reflection reports) a shift in their reactions can be observed. Their answers regarding guidance strategies are more nuanced and profound. For example, before the training their focus would be on having students ‘look back and realize what could have been improved’ (i.e. merely focusing on evaluation), whereas after the training more emphasis on ‘gaining insight into patterns’ and ‘emotions or underlying certain behaviour’ (i.e. more focusing on in-depth reflection) can be observed. Also, teachers mention the aspect of creating a safe environment more often. Another topic that teachers focused more on after the training, appeared to be learning students how to reflect and providing them with feedback.

Considering teachers' assessing strategies we can conclude that teachers stressed the importance of consistency in reflection steps (or answers) when students describe their reflection processes more often after the training. Also, teachers tend to be focusing more on whether students would look forward (as reflection is not only gaining insights from a past situation, but also describing future steps or actions).

The results also indicate that the aspects in the training that contributed most, were the concrete tools that were provided. For example, the rubric to assess reflection, the reflection cards with specific reflection questions, or examples of reflection exercises that can be used for science and engineering students. As indicated too by Mittendorff and Pullen (2019), it seems crucial to provide teachers – and science and engineering teachers in particular - with very clear examples, pictures, or models that show them what can be done (for example, which steps to undertake) or which questions to ask.

4 SUMMARY AND ACKNOWLEDGMENTS

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TO WITHDRAW, INVESTIGATE, NEGOTIATE OR INTEGRATE? STUDENTS' COPING STRATEGIES WITH DISORIENTING DILEMMAS IN INTERDISCIPLINARY PROJECT COURSES

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***Conference Key Areas**: Engineering Skills and Competences, Lifelong Learning for a more sustainable world, Innovative Teaching and Learning Methods*
***Keywords**: engineering education, interdisciplinary education, transformative learning, problem-based learning, disorienting dilemmas*

ABSTRACT

In today's rapidly changing and increasingly interconnected world, engineering educators are required to implement active pedagogical approaches to support students' interdisciplinary problem-solving processes. However, interdisciplinary and experiential learning may evoke situations where students question their past learnings and even existing values, beliefs, or assumptions. Our study examined the emergence of "disorienting dilemmas", a central concept to transformative learning theory, and students' experiences in coping with them in engineering education.

We interviewed ten students from two interdisciplinary project courses at School of Engineering in Aalto University, Finland, and conducted thematic analysis to identify the types of disorienting dilemmas and the coping strategies that students employed. Our study found that students experienced disorienting dilemmas related to self-beliefs, approaches to real-world challenges, teamwork, and disciplinary differences. To cope with these dilemmas, we identified four key strategies that reflected different levels of cognitive-behavioral responses: withdrawing, investigating, negotiating, and integrating.

Our study contributes to transformative learning theory by extending the understanding of disorienting dilemmas in the context of interdisciplinary project-based education. We also provide practical implications for engineering educators seeking to develop students' competencies to effectively address complex challenges in working life. Effective interventions, such as critical reflection, open discussion, and resolving conflicting perspectives, can help students navigate disorienting dilemmas and enhance their interdisciplinary and transformative learning. Future research can explore how students' team characteristics may affect the emergence of coping strategies identified, as well as investigate the impact of scaffolding on students' learning outcomes.

1 INTRODUCTION

The complex societal and environmental challenges call for higher engineering education to equip graduates with key competencies that allow them to adapt to emerging technologies, collaborate across disciplines, and navigate the ethical and social implications of their work (Vehmaa et al., 2018). As such, engineering educators are increasingly applying innovative pedagogical approaches, such as interdisciplinary teaching, project- and problem-based learning, to facilitate students to learn from diverse perspectives, tackle complex problems, and think critically. However, such approaches may also bring obstacles: students can experience difficulties in tackling an unknown problem that requires reflective practice and connecting with epistemologies and discourses that are different from their own (Feng & Hölttä-Otto, 2021; Kabo & Baillie, 2009). While less is studied on how students experience and cope with these challenging situations, it is essential to gain a deeper understanding of student experiences in order to provide support for students learning.

1.1 Defining disorienting dilemmas

The disorienting dilemma concept derives from Mezirow's transformative learning theory, which describes the process of learning through contradictions (Mezirow, 1978). This dilemma is typically the starting point of the transformative learning process and takes place when learners experience a profound sense of dissonance or uncertainty that prompts them to question their prevailing values, beliefs, or assumptions - essentially, the *frame of reference* through which they understand the world. Transformation is achieved when learners critically examine their existing frame of reference and replace it with a new one. This process is considered vital for enhancing critical thinking (Thomas, 2009), fostering greater self-awareness (Jaakkola et al., 2022), and cultivating an overall increased tolerance for uncertainty and ambiguity. These competencies are crucial for effectively responding to sustainability challenges in working life (Rieckmann, 2012).

1.2 Understanding disorienting dilemma in interdisciplinary project courses

Having one's existing frame of reference challenged can cause feelings of discomfort. For instance, Lönngren et al. (2016) identified a high degree of frustration in engineering students when they were tasked to address ill-structured problems due o them requiring different cognitive processes compared to the well-structured problems. Particularly in interdisciplinary engineering education, where project courses integrate engineering, design, and other studies, students are exposed to highly different paradigms or methods (Dym et al., 2005; Hart, 2009). They are required to learn the established techniques that converge to develop 'accurate' answers and uncover 'facts'. At the same time, they need to think in a divergent manner and explore alternative solutions to the problem (Dym et al., 2005). In response to such situations, individual students may exhibit diverse reactions, which in turn can also influence the whole team's coping mechanisms (You, 2023).

Although existing studies have perennially reported students' transformed outcomes of interdisciplinary courses (Tien et al., 2020; Kabo & Baillie, 2009), transformation is not always guaranteed, and not all learning can be considered transformative (Hoggan, 2016). Studies examining transformative learning in interdisciplinary contexts have primarily reported the outcomes of student learning, while neglecting the processes of students resolving disorienting situations. Studying how students encounter disorienting dilemmas and cope with them is the first step toward an in-depth understanding of the key conditions enabling learning transformations where students are more open to various parallel conceptualizations. Therefore, in this paper, we examine students' experiences of disorienting dilemmas in interdisciplinary project courses and their initial responses to them.

Given the quest for providing students with broadened and transformed points of view, our study answers two research questions: (1) what types of disorienting dilemmas do students experience in interdisciplinary project courses, and (2) how do students cope with these dilemmas?

2 METHODOLOGY

This study employed a qualitative case study research design to explore students' learning experiences in interdisciplinary project courses, focusing on how they encounter and cope with disorienting dilemmas. As there are limited studies on students' responses to disorienting situations, qualitative research design was used to gain a better understanding of the phenomenon (Creswell, 2012). Furthermore, we used a multiple-case study methodology to examine different aspects of the phenomenon and analyze the intricate relationships between phenomenon and context (Yin, 2009). Multiple case studies help explain similar results in the studies or argue contrasting results for expected reasons (Yin, 2009). The case study methodology is particularly relevant for the explorative and descriptive nature of the study.

2.1 Data collection

The cases were selected on the basis of their interdisciplinary and project/problem-based characteristics. We targeted courses where students work in interdisciplinary teams to address a joint, real-world problem with external partners from industry and academia. The chosen cases include two master's courses at a Nordic university. Data was collected through an online background survey on their academic and professional background and semi-structured individual interviews conducted by two of the authors. The interviews focused on the emergence of and responses to situations or scenarios where students' assumptions, beliefs, ways of thinking or working were challenged while working on their projects. The interview protocol consisted of open-ended questions designed to elicit detailed responses from the participants about their learning experiences. The interviews lasted approximately 1 hour each and were audio recorded and transcribed verbatim with the consent of the participants. All participants were assigned pseudonyms in data handling process according to the research integrity guidelines.

2.2 Participants

We used purposive sampling to ensure a diverse group of master's students that worked in teams with various disciplinary backgrounds represented, including business, engineering, architecture and design. Students were selected based on their willingness to participate in the study and their availability for an interview 1-2 months before the end of their course. A total of ten students from various design (n=4) and engineering (n=6) disciplines participated in our study. Examples of the disciplines include industrial design, electrical engineering, and mechanical engineering. The students were all participating in one of the two courses studied. Five students attended a problem-based learning course that focuses global sustainability challenges with partners from the industry and academia, while the remaining five studied in a project-based learning course focused on working with real clients on product development. All except two students had less than three years of previous experience in working in interdisciplinary teams at the time the interviews were conducted.

2.3 Data analysis

The initial analysis is informed by an open coding approach (Strauss & Corbin, 1998) identifying patterns and themes that are relevant to our research questions while remaining "open to all possible theoretical directions" (Charmaz, 2006). We continued data analysis with focused and axiel coding iteratively to develop the "most salient categories" in understanding disorienting dilemmas and coping strategies (Charmaz, 2006). Two researchers independently coded the transcripts. Together with the third author, the emerging codes, categories, and themes were discussed through peer debriefing to ensure inter-coder reliability and trustworthiness of the analysis (Lincoln & Guba, 1985). Any discrepancies in coding were resolved through discussion until a consensus was reached.

3 RESULTS

In this section, we present the types of disorienting dilemmas that students encountered in their projects, followed by descriptions of the cognitive-behavioral responses that form the coping strategies of students to those dilemmas.

3.1 Disorienting dilemmas

Four types of disorienting dilemmas emerged from students' responses to their experiences in working in projects: i) beliefs about self, ii) approach to the real-world challenges, iii) approach to teamwork, iv) and understanding of disciplines.

The first type of disorienting dilemma pertains to situations in which students feel that the course has challenged their pre-existing beliefs about themselves and their values. For example, when asked to identify their professional or disciplinary identity, some students struggled to fit themselves into traditional engineer roles, leading them to question what type of engineer they truly are. Additionally, students described how their previous understanding of sustainability issues was challenged by the project, encouraging them to reassess their preconceptions.

The second type of disorienting dilemmas related to the approach to real-world challenges. Students found open-ended problems given by the course partners more difficult to disentangle compared to well-structured problems they are used to solve. Furthermore, they experienced discomfort with the hands-on aspect of the project, which was a departure from their more theoretical studies. Balancing priorities between the team and external partners when coming up with solutions to problems also caused confusion.

The third type of disorienting dilemma was related to the collaborative nature of teamwork. Students described situations where frustration and confusion arose in team settings, which differed significantly from their prior experiences with teamwork.

The final type of disorienting dilemma concerned differences in disciplinary understanding. Students observed epistemological differences that emerged due to differing disciplinary points of view. For example, some students found it challenging to reconcile differences in how engineers and designers justified evidence. They also discovered that their preconceptions about the know-how of colleagues from different disciplines were often inaccurate.

3.2 Coping strategies

Four types of coping strategies towards disorienting dilemmas emerged from our data: withdrawing, negotiating, investigating and integrating. While analysing their characteristics, we found that the four coping strategies include differing behavioral and cognitive responses: these two dimensions can be described as a matrix presented in Table 1. On the behavioral response dimension, students' responses range from reactive to proactive actions: while some students responded by not engaging with the dilemma, others took a more proactive approach to engage with different frames of references. The cognitive responses ranged from maintaining to sense-making: some students resorted to only acknowledging different frames of reference but retaining one's existing beliefs and assumptions, while others responded cognitively by accepting and trying to make sense of new points of view.

Table 1. Cognitive-behavioral responses of students to disorienting dilemmas in interdisciplinary project courses: i) withdrawing, ii) negotiating, iii) investigating, and iv) integrating.

		BEHAVIORAL RESPONSE	
		Reactive	Proactive
COGNITIVE RESPONSE	Maintaining	*(withdrawing)* • Understanding and making space for the more “competent” • Resigning due to different ways of collaboration	*(negotiating)* • Attempting to correct “wrong” assumptions or ways of thinking by others • Utilising disciplinary competencies to showcase one’s perspectives
	Sense-making	*(investigating)* • Understanding the definition of the problem • Questioning the approach to problem-solving • Reflecting the problem from different perspectives	*(integrating)* • Reframing the problem by assessing and balancing students’ and the external partner’s priorities • Synthesizing different ways of thinking or working between disciplines • Creating an environment that encourages integration of views and ways of working

Withdrawing from the dilemma refers to situations when students acknowledge different frames of reference but choose not to engage with the dilemma. For instance, one design student mentioned that engineers had a different approach to problem-solving. Rather than engaging in co-creation with the engineers, the design student decided to give engineers the space to “do their thing”. Similarly in another example, a student thought “it was not worth” to attempt changing teamwork habits of others when their expectations of collaboration were not met and therefore “stopped trying”.

Compared to *withdrawing*, *negotiating* emphasizes one’s proactive efforts in demonstrating one’s perspectives. This coping strategy was particularly prevalent to dilemmas where students saw that others had misconceptions about their disciplinary functions. For example, in one team where a student observed others having preconceptions about design being mainly related graphics, the student had to stand up and find ways to communicate that it was the “wrong” way of seeing design, design research, and designers. Similarly, an electrical engineering student felt that other team members had a preconception of electronics as being “plain magic”. The student decided share resources such as videos for others to understand better what their discipline is about. Another example is from a design student, who made efforts in clarifying their points of view and convincing others to understand through design competencies. When the team asked the design student to work with the prototype measurements, the student realized that it was not possible to do it, but others did not understand. The design student was able to quickly put together a mock-up with paper and drawing to demonstrate the infeasibility of the measurements to the team.

Besides maintaining one's views and ways of working, we found that students also engaged in a sense-making process, *investigating* the project's problem as well as different points of views and approaches to solve the problem. Students were able to reflect and question the definition, the approach, and different aspects of the problem. They paid attention to the problem at hand, by asking questions among themselves and from the external partner to understand and define the problem. For instance, one student challenged their teammates to view the open-ended problem which the student initially found confusing by asking questions on how it could be viewed from different angles. In another project where students were tasked to address a sustainability challenge, they recognized the need to also consider reflecting on other dimensions of sustainability beyond the environmental one which they were the most familiar with from their past studies. When confronted with a dilemma that prompted a student to question their own understanding of sustainability, the student's response was to investigate further why they think a certain way and how might this expanded understanding fit into their frame of reference.

Some students coped with the dilemma through *integrating* to combine different perspectives and ways of working. For example, in dilemmas where students observed potentially conflicting values and demands in designing a solution to fit the partners' needs, students were not only able to acknowledge those values and demands but also actively strived to balance them. One student shared that although there might be clash, there needs to be a continuous effort towards making the solution acceptable to partners while still feeling "good about your outcome". In another example, a student described how their team strived to actively facilitate a "safe environment" for sharing potentially differing views through explaining what they think and why they think a certain way, and everyone should be open to modifying their own views in order to reach a consensus. Furthermore, a student shared an example where, although they (an electrical engineer) and a service designer shared very different views on the problem-solving process, they opted for combining the tools they used for project building.

4 SUMMARY

For engineers, addressing real-world problems while working with a multitude of perspectives can be disorienting. Therefore, engineering educators need to support students to respond appropriately to those disorienting scenarios, be open to new perspectives, and develop greater tolerance for uncertainty (Joslyn & Hynes, 2022). To build foundations for designing educational interventions and providing the kind of support needed for students, our study looks into students' experiences of the disorienting dilemmas and their coping strategies.

We extended transformative learning theory by identifying different types of disorienting dilemmas in interdisciplinary project courses. These include dilemmas about self-beliefs, ways to approach real-world challenges, teamwork, and disciplinary understandings. We also found students' diverse approaches to cope with the dilemmas. The results suggest pathways for engineering educators to engage students to reflect and collaborate across disciplines more effectively. Particularly, when students *withdraw* from the dilemmatic situations, educators can scaffold students in critically reflecting on their assumptions, beliefs and ways of working, for instance, through mentoring or tutoring. Students can also be guided to *investigate* the problem further and *integrate* different disciplinary perspectives and stakeholders' points of view within their project context. By acknowledging these diverse cognitive-behavioral responses to disorienting dilemmas, engineering educators can become more informed to provide appropriate facilitation for interdisciplinary and transformative learning processes.

Our study focused on identifying individual-level dilemmas and coping strategies within a specific institutional context which may limit the generalizability of the findings. Further research can build on our findings by identifying key factors, such as prior experiences, team composition and project brief, affecting the emergence of coping strategies identified. Simultaneously, it is worthwhile to examine how educators can scaffold certain coping strategies that lead to transformative learning outcomes.

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EPISTEMOLOGIES OF ASSESSMENT INSTRUMENTS

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ABSTRACT

Understanding our epistemological perspective when conducting engineering education research is important for situating the knowledge claims we are making. Depending on that perspective, we may situate the knowledge claims as definitive, representing an absolute Truth, or as contingent, representing a contextualized truth. Traditionally, quantitative research has been identified as positivist, while qualitative research is diverse in its epistemological assumptions, ranging from positivist to interpretivist to Critical and the “posts.” Thus, results from quantitative studies are often treated as generalizable, absolute, and decontextualized, while quantitative studies are treated as particular, contingent, and contextualized.

Assessment instruments, being quantitative, are associated with positivist forms of knowledge. We argue that it is more appropriate to treat quantitative assessments as interpretivist. Development of assessments is based on particularized knowledge that is created through a dialogue between the developers and the pilot participants. Interpretation of assessment results is dependent on the particular contexts in which they are used.

In this paper we describe the interpretivist roots of assessment using the example of our current project on developing an instrument for engineering quantitative literacy. In the first phase of this project we have used qualitative content analysis to identify the ways in which quantitative literacy is assessed in first-year engineering courses in the United States. This analysis is contextualized by the particulars of these courses, and the results are contingent on the interpretations we make as researchers. We discuss how this interpretivist perspective carries through the entire project as we create and implement a measure of quantitative literacy for engineering students.

1 INTRODUCTION

At its core, research is the practice of making knowledge claims from empirical evidence. How we make these knowledge claims depends on our views of how knowledge is defined, or our epistemological beliefs. Epistemology is the nature of knowledge; what counts as knowledge, how we understand what knowledge is, and where knowledge comes from (Crotty 1998). Being explicit about one's epistemological assumptions provides transparency in the research process and helps researchers select appropriate methodologies that are coherent with those assumptions (Koro-Ljungberg et al. 2009, Douglas, Koro-Ljungberg, and Borrego 2010). Studying the same phenomenon from different epistemological perspectives can provide a more holistic view that would not be possible from a single perspective (Baillie and Douglas 2014, Douglas, Koro-Ljungberg, and Borrego 2010).

In this paper, our goal is not to report results from our study but to expand notions of epistemological diversity. In particular, we seek to disrupt the assumption of quantitative research as inherently positivist. Modern Western notions of science default to a positivist epistemology, with its assumptions of objective Truth. Quantitative research is viewed as objective and neutral, allowing us to identify that Truth. We argue that in social sciences generally, and in engineering education in particular, even quantitative research should be seen as non-positivist. As an example case, in this paper we discuss how we have considered epistemology in our current research project to develop a quantitative instrument for engineering quantitative literacy.

2 LITERATURE REVIEW

2.1 Epistemology

Broadly speaking, epistemologies can be grouped into four categories: positivist, interpretivist, Critical, and the 'posts' (post-structural and post-modern). Positivism is generally associated with quantitative research, although qualitative research can also be conducted from a positivist perspective. Positivism assumes that there is a single objective Truth that exists independently of humans. The goal of research is to identify that Truth, although empirical claims are always subject to falsification. Positivism has important implications for how research is conducted. In quantitative research, instruments should be reliable to ensure that they consistently measure the construct of interest. Positivism also implies the need for large sample sizes in order to separate the true effect from noise. And statistical analysis is needed to determine how likely it is that our data represents a true effect (e.g., the use of p-values in hypothesis testing). In qualitative research, positivism results in the need to have multiple coders and to calculate the inter-coder reliability. Since there is an objective Truth in the data, two different coders should code the data the same way.

Interpretivism is generally associated with qualitative research, although the thesis of this paper is that quantitative research can also be interpretivist. Interpretivism recognizes that there is no single Truth, but rather multiple truths that are created through people's interaction with the world. Thus, truth is contingent and contextual. Interpretivism in the context of assessment is discussed further in the next section.

A Critical epistemology takes knowledge to not only be contingent, but subject to politics (i.e., the struggle for resources). Thus, Critical research examines issue of power and seeks to disrupt existing power relationships. There are various Critical approaches, each with its own set of tenets. QuantCrit specifically addresses the issue of quantitative data with tenets that neither numbers or categories are value-neutral (Suzuki, Morris, and Johnson 2021). It recognizes that presenting quantitative research as 'objective' can mask the ways it is used to maintain racial hierarchies. 'Post' epistemologies take knowledge to be embedded in grand narratives that describe the way the world 'should' be. The role of 'post' research is to disrupt those narratives.

2.2 The Epistemology of Educational Assessment

Epistemology is not often discussed in engineering education research articles, particularly those with methods using educational assessments or surveys. While it is often unacknowledged, the researchers' epistemology can be understood from how the study's methodology is approached and results discussed (Koro-Ljungberg and Douglas 2008, Koro-Ljungberg, et al. 2009). Are the researchers approaching the study from the perspective that their own interpretation is part of the research process? Or perhaps the researchers make statements that indicate the results somehow speak for themselves and there is no researcher finding. In the case of educational assessment, the researchers' epistemology may be unclear or even seemingly conflicted between the use of an assessment and the conclusions drawn.

Researchers in the measurement community have long communicated that subjectivity and interpretation are inherent in all aspects of educational assessment (e.g., Thorndike and Hagen 1977, Messick 1998), but rarely does one find practical discussion of what these aspects mean for research and educational use (e.g, Smith 1989). Thus, scores resulting from assessment instruments are too often interpreted simply as a valid measure and there is no variability of interpretation (Douglas and Purzer 2016). Many students have been evaluated based purely on a resulting assessment score, without contextualization of the subjectivity of the assessment or the values of the assessment developer. Such an approach is misaligned with the constructivist nature of educational assessment. Hence, discussion of epistemology is warranted to remind engineering education researchers, administrators, and educators to treat assessment scores with a degree of humility and to challenge the community to develop assessments with interpretivist or critical considerations explicitly in mind.

The beginning of any assessment is to define what is to be measured and the scope. Cronbach and Meehl (1955) defined the term *construct* as, “some postulated attribute of people, assumed to be reflected in test performance” (p. 4). Considering no one can see inside another’s mind to know what is understood, thought, or felt, the assessment developer must first decide what the construct definition is, and then how it will be measured. Put another way, educational assessment seeks to define what should be measured, then create opportunities where the student can demonstrate their knowledge, attitude, etc. in a way that assessment users can then use to draw reasonable inferences about what the students know (Pellegrino 2013). In short, the assessment developers construct what will be assessed, how it will be assessed and how it will be used and interpreted. Thus, subjectivity is an inherent characteristic of all assessment, from development through to decisions and resulting consequences. “The test score is not equated with the construct it attempts to tap, nor is it considered to define the construct, as in strict operationism. …the measure is viewed as just one of an extensible set of indicators of the construct” (Messick 1989, p.7). Years later, Messick (1998) wrote more directly, “constructivism is central to the whole enterprise of construct validity” (p.35). While the scientific or mathematical knowledge represented in educational learning goals may have concrete truths (e.g., mathematically, 4+4 equals 8), the process of measuring that mathematical principle is constructed.

The constructivist nature of assessment necessitates that there is no such thing as a perfectly valid assessment (Songer and Ruiz-Primo 2012). Unlike measures used in fields of engineering that reflect a scientific principle (e.g., volume is measured by the same equation around the world), educational assessments attempt to measure constructs that the reality of existence can scarcely be proven. People construct the name, what it means, and how to measure it. Validation is intended to be the evaluative process regarding what inferences can reasonably be made and uses for the scores are justifiable. As we cannot see directly into someone’s mind, there’s no one ‘right’ way to measure what they know and can do. Thus, some scholars have argued that educational assessment attempts to measure something far more difficult than the physical realm measured by engineers (Douglas and Purzer 2016, Wankat et al. 2002). It is precisely the difficulty of measuring something that is not observable that formed the field of educational measurement and psychometric techniques. However, those techniques do not change the inherent nature of educational assessment – from start to finish, the developers and users make subjective decisions. Psychometric methods are the statistics concerned with modelling measurement error. This acknowledgement in the statistical methods that all educational measures are imperfect tools is misaligned when assessment scores are summed up, graded right/wrong and then used from a positivist perspective.

Despite common understanding that all educational assessments are value-laden and subjective, judgments made about students or groups of students based on assessment scores seem to reflect a 'truth' that the score is in fact all the researcher, educator, or administrator need to know (Smith 1989). Mislevy (1994) discussed how researchers of different paradigms (behavioural, information processing, and constructivist) might approach validation studies in terms of evidence collected and inferences sought. Simply acknowledging that researchers have different epistemological understandings is exactly the reason why researchers approach their work from the perspective that they themselves cannot be separated from the research. What evidence is collected and the scientific argument for why that evidence is sufficient is subjective. What constitutes 'enough' or 'good enough' is highly context dependent, as standards argue that the more a test is used for decisions of personal consequence, the more evidence is warranted (AERA, APA, and NCME 2014). Assessment frameworks and standards are intended to increase the principled nature of developing, validating, and using assessments (e.g., Evidence-Centered Design, Mislevy 1994, Argument-Based Approach, Kane 2016).

Ethical approaches to assessment acknowledge the diverse ways people know, experience, and demonstrate their knowledge. From cognitive science research, we understand that learning is mediated by culture, language, and other tools (National Academies of Sciences, Engineering, and Medicine 2018). The sociocultural-informed Evidence-Centered Design approach (Oliveri, Nastal, Slomp 2020) is an assessment design and validation model that explicitly considers how diverse groups of students would experience, understand, and demonstrate their understanding in diverse ways. Without this explicit acknowledgement, the assessment developer runs the risk of assessing students in the way they themselves demonstrate understanding and then holding students from different socio-cultural backgrounds to the same way of knowing.

3 THE CASE – ENGINEERING QUANTITATIVE LITERACY

As the goal of this paper is to discuss the epistemology of assessment, here we provide only a brief overview of our current project to develop an instrument for engineering quantitative literacy. More details are provided in a recent paper (Fenner et al. 2023).

Quantitative literacy (QL) is the ability to engage in context-specific quantitative activities for problem solving. The chapters in the book edited by Gillman (2006) provide an overview of how QL is taught across the curriculum at a number of institutions. There are a number of definitions of QL (AACU 2014, Mayes, et al, 2013, OECD 2012, Sons, 1996, Vacher, 2014, Wilkins, 2010). There is a consensus among these definitions that QL consists of mathematical skills, communication of quantitative information, interpretation and reasoning, and ability to apply these elements in particular contexts. Wilkins (2010) identified three components of QL: disposition, beliefs, and cognition. The cognition component can be further divided into content, reasoning, and communication (Roohr, Graf, and Liu 2014, Kosko and Wilkins 2011), and thus the cognition component encompasses the elements of the other definitions. While a number of instruments have been developed to measure QL skills (see, for example, ETS 2021, Kosko and Wilkins 2011, Zahner et al. 2021), existing instruments were designed for grade school, general college students, or the general adult population.

While there is broad agreement that quantitative skills are critical for engineers, there has been almost no work done on the QL skills of engineering students. Prince and Simpson (2016) have written the only paper which focused entirely on engineering students. The goal for our project is to develop an instrument for engineering QL, which can then be used to assess the QL skills of engineering students.

Our overall project uses the Evidence-Centered Design process (Mislevy, Almond, and Lukas 2003), a comprehensive framework for designing and validating assessments. In this framework one articulates assessment arguments in each of three models in an assessment: Student Model, Evidence Model, and Task Model (Riconscente, Mislevy, and Corrigan 2016). We are currently developing the Student Model, which defines what we will measure, i.e., the variables related to the knowledge, skills, and abilities we want students to learn.

To develop the Student Model, we first developed a definition of QL. Based on our review of the literature, we defined QL as

> *The ability to engage in context-specific quantitative activities for problem-solving and communication by collecting, understanding, processing, interpreting, synthesizing, and displaying numerical information. This definition includes numerical skills and dispositions, and beliefs in quantitative activities.*

We then collected course syllabi, assignments, and exams for first-year engineering courses at five institutions in the U.S. We developed a coding frame based on our definition of QL and the components of QL described above. The course materials were then coded by the first two authors, with the third and fourth authors reviewing the coding as a check on quality. It is important for the discussion below to note that we did not calculate an inter-coder reliability. Codes were discussed among the authors and discrepancies were resolved through consensus.

Out of 125 QL tasks in the course materials, all fell into the Cognitive dimension, with none in Beliefs or Dispositions. Within Cognition, 85.6% were coded as Reasoning, 9.6% as Communication, and 4.8% as Content. Examples of the tasks and further discussion of these results is given in our prior publication (Fenner et al. 2023). We are continuing to develop the Student Model by categorizing the types of QL tasks that are present in our data.

4 EPISTEMOLOGY IN PRACTICE

Initially we implicitly conceptualized this project as positivist. Our definition of QL gave us a specific, detailed description of what constituted QL tasks that we intended to use to characterize tasks in the course materials. Our assumption was that the definition provided a clear, unambiguous way to identify QL tasks that would be valid regardless of the specific document we were analyzing.

However, as we began analyzing the data and discussing the coding, we recognized and questioned our positivist assumptions. Each course was taught in a specific context, to a particular group of students, and thus each course had a particular focus. Our analysis of what constitutes QL in engineering is thus shaped by those contexts. We also realized that, despite its apparent specificity and clarity, our definition ultimately required us to rely on our own interpretive skills in order to assign each task to an appropriate QL dimension. The contextual and interpretive nature of the data is apparent at three levels: course, instructor, and task.

At the course level we noted that most of the content focuses on circuits. While we do not yet know if this focus will be present as we collect materials from more schools, it does impact how QL is ultimately defined. QL skills based on circuits may be different from those based on structures, for example. The instrument we ultimately develop must therefore be understood as contextualized based on how it was developed, and not represent an absolute, objective measure of QL.

At the instructor level, one of the coders teaches courses in linear circuits. Thus, during coding with tasks associated with linear circuits, she became aware of the need to 'bracket' her assumptions about what she would expect students to do, and only code based on what the assignment actually said. This need to bracket one's own biases is an element of qualitative, interpretive research. Bracketing results from the lack of a single, objective Truth that is present in all contexts.

At the task level, we found that our QL definition was not unambiguous and required us to interpret what it meant for a given task. For example, activities related to Kirchhoff's Current Law appeared frequently in the student materials. Kirchhoff's Law can be summarized as: for any node in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node. Initially, we assumed that any task or assignment involving Kirchhoff's Law was a QL task because Kirchhoff's Law requires some sort of mathematical understanding as marked by the terms "equal to" and "sum of." However, the interpretation of quantitative literacy as an interpretivist construct led us to question the assumption that all tasks requiring mathematical skills are necessarily QL tasks. Through our encounters with different types of tasks, we came to the realization that some activities may require students to apply mathematical concepts or solve problems, while others may demand a different set of skills altogether. For instance, while one task might call for students to work through a problem using Kirchhoff's Law, another might ask them to explain this law in simpler terms suitable for a non-expert audience such as grandparents or readers of a newspaper article. Thus, whether or not a particular tasks involves QL requires an interpretation of what QL means in that context.

5 SUMMARY AND ACKNOWLEDGMENTS

Our experience shows how quantitative research in engineering education is interpretive. While most of engineering is positivist, e.g., a given circuit has predictable behavior, the same cannot be said of research involving human subjects. Our experience with QL assessment development shows the ways in which quantitative instruments are more appropriately considered from an interpretivist perspective. Thinking of QL from a positivist perspective implies a singular definition, with assessment results that objectively identify a student’s QL skills. However, our literature review and experience with this project show that assessment results need to be understood as contextualized and subjective (i.e., subject-focused). As we proceed in our project, our assessment of QL skills will need to be considered as situated. They will be based on a particular way we have defined QL and operationalized that definition. Other definitions and operationalizations, equally relevant, could have different results. In addition, we will need to interpret the results in light of the students who respond to the instrument.

Considering assessment as interpretivist rather than positivist has important implications. Traditional measures of quality, such as reliability, are not sufficient for ensuring appropriate use of assessment instruments. Instead, researchers need to be reflexive about the context in which the assessment is occurring and their own biases. In selecting instruments, researchers should ask themselves questions such as: In what context was the assessment instrument created? How does that compare to the context in which I am using the instrument? How do I understand the topic and how has that influenced which assessments measures I chose? In interpreting the assessment results, questions include: What contextual factors might affect these results? How does my understanding of the topic influence my interpretation of the results? How would students from different socio-cultural backgrounds respond to this assessment? What are the consequences resulting from the intended use of the assessment results?

We question whether any engineering education research, quantitative or qualitative, should be considered positivist. Given the subjective nature of human experience, any research on human subjects needs to account for this subjectivity. As stated by Suzuki, at al. (2021), “numbers are never neutral, because they are used by humans, and therefore filtered through human biases” (p. 538). Viewing quantitative research from an interpretivist (or Critical or “post”) perspective will provide richer, more complete understandings.

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EMERGING TRENDS, APPROACHES AND CHALLENGES IN ENGINEERING EDUCATION IN THE UK

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Conference Key Areas: *curriculum development; innovative teaching and learning methods; virtual and remote education in a post Covid world.*
Keywords: *engineering curriculum; models of engineering education; instructional methods*

ABSTRACT

Worldwide, engineering educators are searching for approaches, pedagogies and change strategies to develop programmes that will equip their graduates to be successful engineers, effective engineering leaders and catalysts for social

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development. In the UK, focus largely rests on new pathway initiatives and new Higher Education (HE) institutions. There is little shared understanding of the established sector’s evolution from a maths and science heavy curricula to the innovative and world-leading models of engineering education found in the UK HE sector today.

This research paper looks at examples of trends that are emerging in engineering education provision in the UK and highlights case-studies of innovative provision and new models in the sector. A mixed-mode approach of desk research, structured survey and case studies were used to collect data. Data analyses show that across the UK there is a complete spectrum of engineering higher education, with the reality of the provision being complex with a broad diversity of educational models on offer. The research reviews current teaching and learning approaches and highlights evidence of innovations in laboratory practical teaching; use of projects; dissertation projects; project-based learning, project-based initiatives and frameworks; and examples of new buildings driving curriculum innovation.

In particular, the paper presents and discusses data concerning current teaching and learning approaches (including barriers and impact of the coronavirus on learning approaches and provision of engineering education in the UK), information on innovative elements, and COVID mitigation and engagement with new methods of delivery.

1 INTRODUCTION

Engineering education has been responding to call from industry, from students and from professional bodies for change to ensure graduates are ready for the work environment and prepared to face the global challenges of the 21st century. This has led educators to implement change strategies to develop programmes that will equip their graduates to be the successful engineers, effective engineering leaders and catalysts for social development. In the UK there have been government-led initiatives (for example degree apprenticeships), entirely new institutions (for example, NMITE (New Model in Technology and Engineering), TEDI London (The Engineering Design Institute London) and Dyson Institute) as well as evolutions of established programmes or new programmes in established institutions. These developments have all been established in the context of a shifting landscape of student funding, including a growth in international student numbers and falling (when adjusted for inflation) funding for UK students just as the numbers of UK 18-year-olds is starting to increase.

In this paper we aim to paint a picture of the UK Engineering Education sector and look at the prevalence of key approaches to teaching and learning to better understand how the sector is evolving. We will present the results of a survey of engineering education leaders in higher education institutions across the UK supplemented with public data-sets. We show that the professional development of engineers at this higher level is not a single track although certain trends and approaches emerge as being dominant approaches.

2 METHODOLOGY

This work takes a mixed-mode approach of desk research, structured survey and case studies development to collect data. The survey data reported in this section is drawn from an online survey of Engineering Departments undertaken between June and early September 2022. Two versions of the survey were administered, one targeted at faculty level strategic leaders (Deans/Vice-Deans or Associate Deans Education) and one at the Department/Disciplinary Level. The first survey link was sent to all Deans of School/Faculties which contain an engineering activity and where they could be identified all Vice-Deans Education, Associate Deans Education or Directors of Education. The second survey was sent to all Heads of Department and where possible departmental teaching leads. Data is drawn from the Higher Education Statistics Agency (HESA) Staff and Student data-sets. The HESA student data includes the Common Aggregation Hierarchy (CAH) 10-1 group codes which covered Engineering subjects (but not computing or materials science) and uses student Full Person Equivalent (FPE) as recorded by HESA. it considers first degree (including Foundation year) including bachelor's degrees (BEng) and integrated masters (MEng) and includes programmes in England, Scotland, Wales and Northern Ireland.

3 RESULTS

3.1 Engineering education provision in the UK

Desk research illustrated that across the UK there is a complete spectrum of engineering higher education, with the reality of the provision being complex with a broad diversity of educational models on offer.

- 109 UK universities offer undergraduate engineering degrees (not including software engineering)
- All UK universities teaching engineering offer either BEng (Framework for Higher Education Qualifications (FHEQ) Level 6) – including a few only offering BEng top-up – *or* Integrated MEng (Level 7) courses.
- Most UK universities teaching engineering offer *both* BEng (FHEQ Level 6) *and* Integrated MEng (Level 7) courses.
- Most UK universities offer one-year postgraduate taught masters' courses.
- Four UK universities only teaching engineering at postgraduate level (Level 7) – although only one at scale.
- Nearly three quarters (72%) of UK universities are advertising at least one foundation year option (in some cases, a university's foundation year will be taught at a local Further Education (FE) college). Note that degree programmes in Scotland are typically a year longer, so the foundation year model is not evident.
- Nearly one quarter (23%) of UK universities offer an Higher National Certificate (HNC) (level 4), Higher National Diploma (HND) or Foundation Degree (level 5).
- Several UK universities offer a 'top-up' year to complete a BEng degree, even where they do not offer level 4 or 5 qualifications.
- Nearly a third of the universities offer part-time study of undergraduate engineering (32%) but this is typically as part of a degree apprenticeship, top-up degree or at universities offering non-degree level courses.

- Nearly one quarter of universities offer the opportunity of a year-long industry placement or the chance to study abroad for a year.
- Although a large number of universities are involved in the delivery of engineering degree apprenticeship, the majority deliver only one or two standards in engineering with only 9 delivering more than three.

Alongside traditional titles such as mechanical, civil, electronics or chemical, undergraduate students can enrol at undergraduate level for courses including: Motorsport Engineering; Energy and Sustainability Engineering; Civil and Geo-environmental Engineering; Coastal and Flood Engineering; Offshore, Subsea and Pipeline Engineering; Structural and Fire Safety Engineering; Yacht Design and Production; Aeronautics and Astronautics with Engineering Management; Electronic Engineering and the Internet of Things; Robotics and Embedded Systems Engineering; Biomaterials and Tissue Engineering; Design, Innovation and Creative Engineering; Ordnance, Munitions and Explosives.

The opportunities for postgraduate study are even more varied and specialised with frequent interdisciplinary links e.g., with computer science and technology, medicine, architecture, management, and the full range of physical and biological sciences. Expertise in the engineering departments of our world-renowned universities demonstrates the global recognition of engineering in the UK HE-sector. Meanwhile, regional context or links with local industry frequently allow individual universities their own engineering specialisms reflecting the transformative role of the Higher Education institutions in their own individual setting.

3.2 Scale of engineering education provision in the UK

The data shows that the total number of students (FPE) studying engineering at first-degree or on a postgraduate course in the academic year 2020/21 is 149,725. It shows that 79.8% are studying at English HE institutions, with 12.3% in Scottish, 5.5% in Welsh, and 2.5% in Northern Irish HE institutions. If considered by region it can be seen there is a strong presence of engineering schools and engineering students right across the UK.

When we rank the size of individual providers, we see that there is considerable variation in the scale and make up of institutions. The largest institution in the UK is the Open University which offers flexible distance and open learning part-time study, predominantly for UK at undergraduate level. On the left-hand side of Fig. 1, we see a small number of very large providers with 4,000-5,000 students, around 20% at postgraduate taught level. There institutions will typically offer a wide range of engineering disciplines almost always including, Electrical engineering, Mechanical engineering, Civil engineering and Chemical engineering. We then see a wide range of institutions with between 1,000-3,000 students. Here there is more diversity in disciplines offered, with some also offering general engineering entry routes with specialisation later in the degree. The majority will offer Electrical engineering, Mechanical engineering and Civil engineering. Finally, around half of the institutions that return data relating to engineering subjects have total cohorts of less than 1,000 students, often offering a more specialised range of engineering subjects and typically part of broader science and engineering faculties. Although over 100 institutions are represented here, the largest 30 admit over 60% of the total engineering student body.

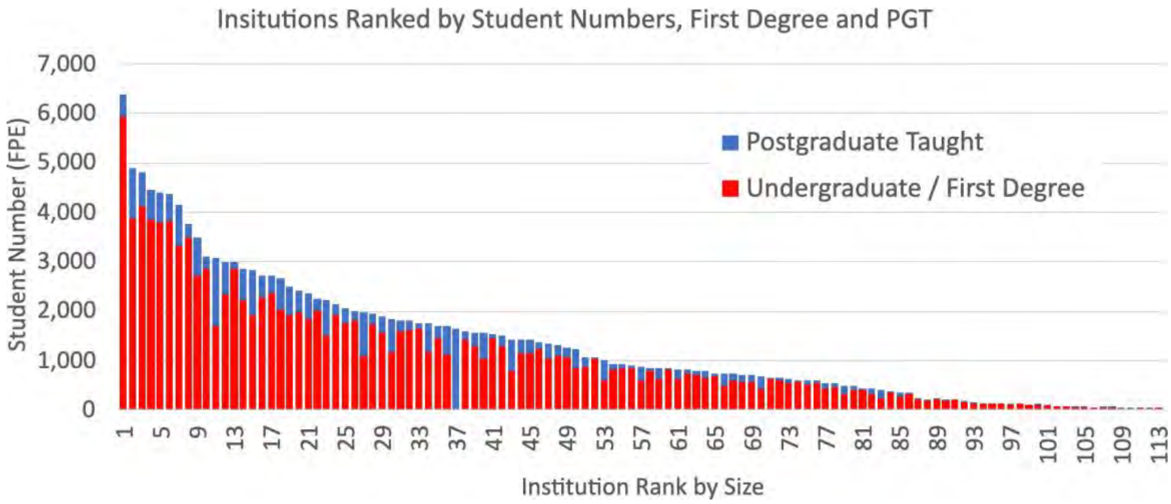

Fig. 1. Size by Student Number of UK HE Engineering Providers, First Degree and Postgraduate Taught (PGT). Source: HESA Student Record 2020/21

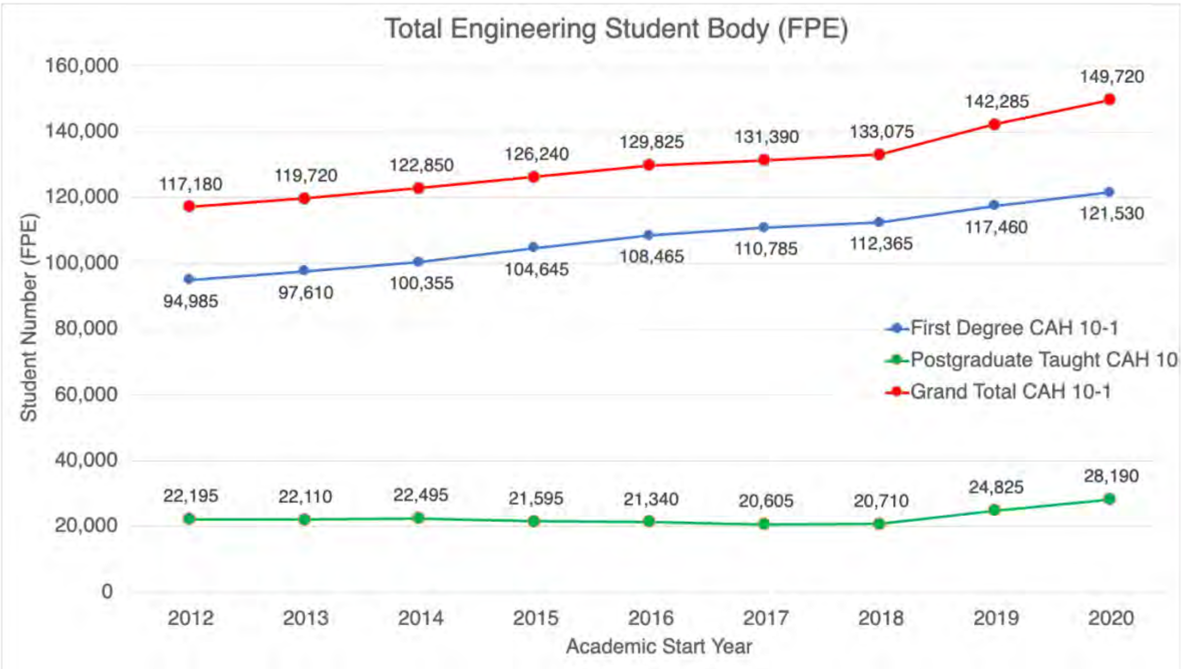

Fig. 2. Trends in UK Engineering Student Numbers 2012/13 and 2020/21. Source: HESA Student Record 2012/13 to 2020/21

3.3 Trends in engineering education provision in the UK

In 2020/21 engineering students made up around 5.5% of the total student population in the UK having risen from 5% over the decade from 2011/12. The majority of this growth is at first degree level – rising from 5.3% of the total student population in 2011/12 to 6.1% in 2020/21, against a fall in Postgraduate taught numbers which have fallen from 4.1% to 3.8% in the same period.

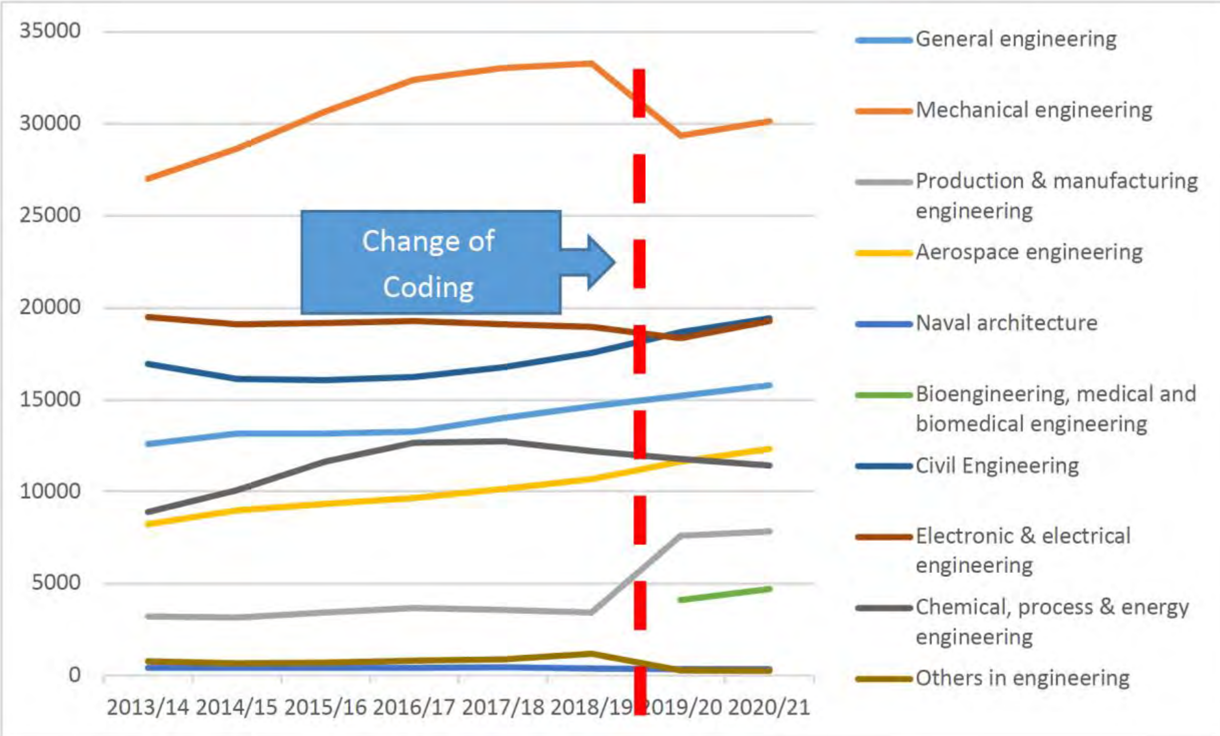

Fig. 3. Trends in UK Undergraduate Engineering Student Numbers 2012/13 and 2020/21. Source: HESA Student Record 2012/13 to 2020/21

If we look at specific disciplines, as shown in Fig. 3, we see that undergraduate level Mechanical engineering remains the most populus discipline. Although Electronic and electrical engineering is taught in slightly more institutions (81 institutions reported more than 50 students compared to 77 for Mechanical engineering) there are more large Mechanical engineering departments with 28 reporting more than 500 students (compared to just 12 for Electronic and electrical engineering). We should note that in Fig. 3 for first degree and Fig. 4 for postgraduate taught programmes that the coding scheme used to record disciplines changes between the 2018/19 and 2019/20 academic sessions. Therefore, the sudden jumps in certain disciplines, and the appearance of Bioengineering, medical and biomedical engineering as a discipline are likely to be predominantly due to this coding change rather than any change in the student body. Despite this, at postgraduate taught we do see some significant shifts in some disciplines, most notably the rise in Electronic and electrical engineering and Production and manufacturing engineering.

3.4 Current teaching and learning approaches

Competition amongst providers, developments in learning technology, initiatives from government and pressures for industry and regulators have led to significant developments in the approaches to engineering education in the UK over the last decade. Despite this there is still a conception that all engineering education at university level can be characterised is being heavy in maths and sciences, with applications only developing in later years. This is in line with what David Goldberg in the US (Goldberg and Sommerville 2014), characterised as the maths/science death march of engineering education. While it is undoubted true that this has been the case, our research has shown that within the majority of institutions there are developments towards more student-centred and active-learning approaches that have been advocated for by thought leaders in engineering education for some time. Our review shows a complex picture across the UK with spectrum educational models on offer. In this section of the report, we will look at examples of trends that are emerging in engineering education provision in the UK and highlight case-studies of innovative provision and new models in the sector. We highlight evidence of laboratory practical teaching; use of projects; dissertation projects; project-based learning, project-based initiatives and frameworks; and examples of new buildings driving curriculum innovation. This falls very much inline with the directions of travel identified in the 2018 MIT report, Global State of the Art in Engineering Education (Graham 2018) which places the programmes delivered in the UK in a global context.

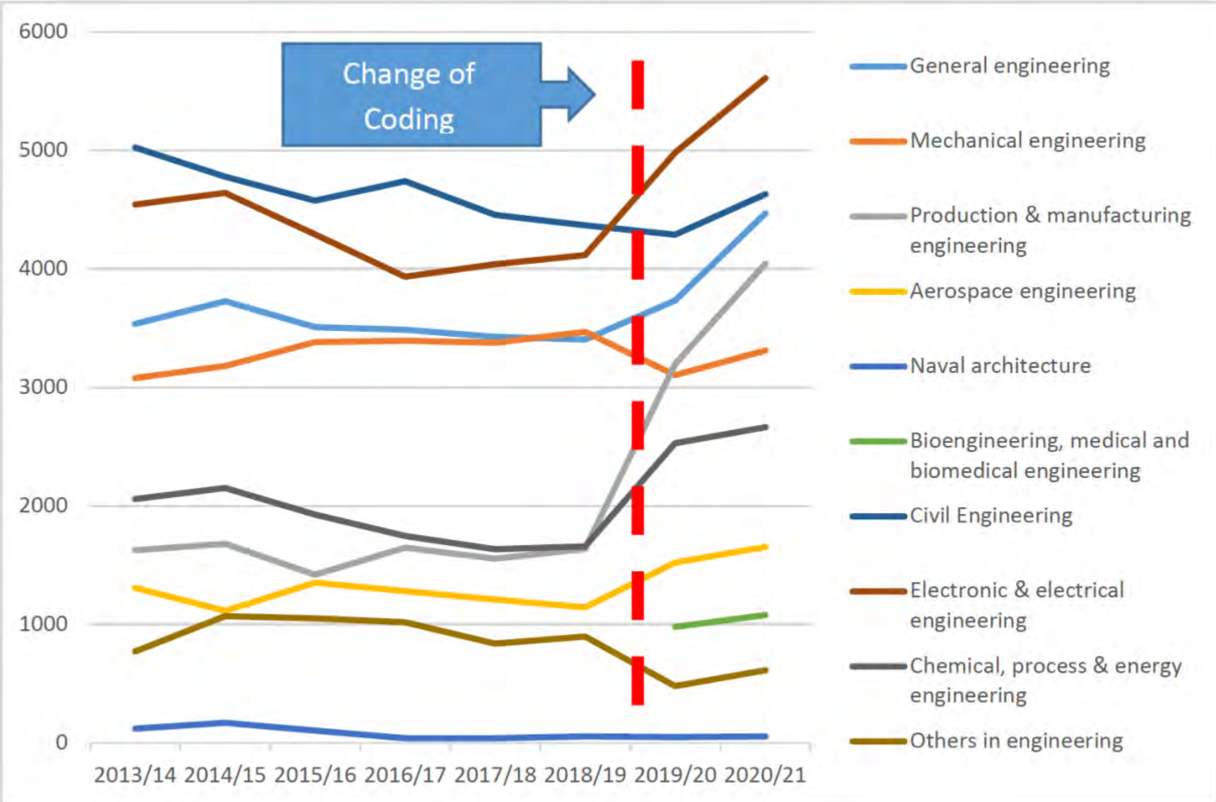

Fig. 4. Trends in UK Postgraduate Engineering Student Numbers 2012/13 and 2020/21. Source: HESA Student Record 2012/13 to 2020/21

3.4.1 Active learning

As part of the survey, engineering department leaders were asked the proportion of courses/modules that implement active learning as the dominant form of teaching. For most respondents, active learning is reported as the dominant form of teaching in 25% to 75% of the courses/modules taught at UG level. Overall, active learning is implemented at a higher proportion of courses in UG in comparison to PGT level. However, the proportion of teamwork activities in engineering programmes is lower. It varies between 25 and 50% for most UG programmes and less than 25% for most PGT programmes represented in the survey.

The analysis of participants' responses to the question "Can you give an example of active learning at your department that works particularly well, and why?" suggested that what 'worked well' was associated with the following student outcomes: skills development and deeper understanding; workplace-related projects and skills; thinking beyond their discipline; higher enthusiasm and creativity. Examples of active learning activities included: group work and/or teamwork, competitions, interdisciplinary projects (including design, build and test), work-based learning and fieldwork, entrepreneurship challenges and courses, and flipped classrooms.

3.4.2 Practical teaching

Engineering is commonly viewed as a practical discipline. As we have seen above, active learning and projects are key element of the modern engineering education experience. In the survey, we asked departments, what types of hands-on/practical learning approaches are used in their engineering programmes, and to provide examples of the most relevant approaches. All engineering programmes represented in the survey use hands-on/practical learning approaches, in both UG and PGT programmes, and across all years. The most relevant approaches are predominantly 'projects', including research and design projects (including digital design), in teams or individually. Other frequently mentioned approaches used to develop experimental practical skills included 'laboratories', 'workshops' and 'makerspaces'. 'Experiments' included laboratory work or classes, as well as home experiment kits or remote experiments. Other approaches mentioned included 'testing' (e.g. mechanical, circuit design and test, materials testing), 'computer-aided design', 'fieldwork' or observations (e.g. land surveying and site visits).

3.4.3 Barriers and impact of the coronavirus on learning approaches and provision of engineering education in the UK and COVID mitigation and engagement with new methods of delivery

The survey looked into how engineering schools approached teaching and learning as a response to covid-19 pandemic. As expected, practical activities were substantially reduced, with virtual labs and take-home kits taking a significant increase. Provision was put in place to allow students to be able to download specialized software onto their own machines. Other activities included labs with adequate measures (such as physical distancing) and small group activities on campus. Considering the upcoming academic year (2022/23), engineering schools were asked to rate a set of statements using a scale ranging from 1 (extremely unlikely) to 5 (extremely likely). Respondents were more likely to change provision in order to include more use of online simulation tools (M=3.83), use of blended/hybrid modes of instruction (M=3.76) and use on pre-recorded lectures (M=3.55) than in pre-pandemic times. They were less likely to use virtual placements (M=1.83) and take-home kits (M=2.26). There were more likely to use blended/hybrid modes of instruction, use of online simulation tools, pre-recorded lectures. Despite some success and some advantages being observed, there were less likely to use virtual placements, take-home kits, as well as live online lectures.

3.5 Innovation case study

A common feature of the majority of developments reported is the renewed emphasis on project-based and practical teaching. This demonstrates a significant allocation of staff time and in some cases significant investment in new laboratories. For examples, the Department of Multidisciplinary Engineering Education based in the new Diamond Building at the University of Sheffield have used these cross-faculty facilities to pioneer an approach to offering practical teaching based on innovative practical laboratory sessions at scale to departments across the faculty (Garrard, Bangert and Beck 2020). Recently the School of Engineering at the University of Birmingham has introduced Integrated Design Projects (Cooke et al. 2018) as part of a common first year of study before specialisation in a discipline. Through the Integrated Engineering Programme (IEP) UCL has introduced a 'thread' of project-based learning experiences throughout the first two-years of the programmes (Mitchell et al. 2021). A number of institutions reported implementing CDIO (Edström and Kolmos 2014) as a framework to increase the number of project activities within their programmes. Examples include Aston University (Thomson and Clark 2018). Queen's University Belfast (Hermon and Cunningham 2011) and most recently Canterbury Christchurch University. Another initiative that is starting to gain momentum is Vertically Integrated Project (VIP) with examples at the Universities of Strathclyde (Strachan et al. 2019) and St Andrews (Coyle et al. 2021).

4 SUMMARY

Our review of the engineering higher education sector within the UK shows that student numbers and the popularity of engineering as a discipline continues to grow in a sector that has a diverse range of offerings and that is, perhaps more slowly than some would like, embracing new teaching methods included the development of practical and project based teaching throughout the curriculum.

5 ACKNOWLEDGMENTS

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How do students use basic aspects of functional thinking when learning mathematics in a chemistry context?

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ABSTRACT

The mathematical concept of function is challenging for students in first-year undergraduate mathematics courses, especially when the concept is applied in the context of STEM courses. This difficulty is often due to a lack of conceptual understanding of functions. From a normative perspective, conceptual understanding of functions involves 1) dealing with the different representations of a function, namely table, graph, analytical term and verbal description, while 2) considering three different aspects of functions, namely correspondence, covariation and object. Previous research suggests that the covariation aspect is essential for achieving a sophisticated conceptual understanding of functions. In order to promote the conceptual understanding of functions, a digital self-learning environment was developed and implemented in the first-year basic mathematics course at the School of Life Sciences, University of Applied Sciences and Arts Northwestern Switzerland (FHNW). To facilitate the transfer of mathematical knowledge to applied STEM courses, the mathematical learning environment focuses on chemical reactions, where the concentration of the reactants is analysed. Initial findings from the qualitative content analysis show 1) how students use the different aspects of mathematical functions in the context of chemical reactions and 2) how the covariation and object aspects support students in linking the chemical context to mathematical representations.

1 INTRODUCTION

1.1 Mathematical Functions in Life Sciences

The application of mathematical functions is important in many STEM applications, as they are frequently used to describe real-world phenomena (Rogovchenko and Rogovchenko 2022). Therefore, a conceptual understanding of functions is a prerequisite for students entering STEM studies at university (Eberle et al. 2015; Neumann, Pigge, and Heinze 2017) even though many have problems dealing with them (Bain and Towns 2016; Ivanjek et al. 2016). One source of difficulty may be that functions, as an abstract concept, are only accessible through external representations (Duval 2006). The most common representations of functions are graphs, tables, algebraic equations and verbal descriptions. The latter can be considered as a situational description when a real-world context is given, e.g. every 20 minutes the number of cells doubles. To develop a sophisticated understanding of functions, one should be able to switch flexibly between these representations and know which is more appropriate for a given task. Research suggests that switching between representations is more difficult when a situational description is included (Bossé, Adu-Gyamfi, and Cheetham 2011), so it is expected that students will struggle to interpret graphs and the situational meaning of given parameters in algebraic equations.

Chemical kinetics, a subfield of physical chemistry, “is one of the areas that utilizes mathematics as its primary representation to communicate observations, analyses, and interpretations” (Bain and Towns 2016). It analyses the mechanisms of chemical reactions, focusing on reaction rates and the factors that influence those rates. This can be done by measuring the change in reactant concentration over time. The most basic chemical reactions are of zero and first order and can be described accordingly using linear or exponential functions (Elstner 2017). Several qualitative studies have reported the difficulties students have in interpreting graphs in chemical kinetics and in transferring knowledge from mathematics to chemistry and vice versa. Students tend to have a static view of the graph and associate it with specific phenomena, i.e. a Michaelis-Menten curve. This can be problematic when similar graphs occur in different applications and when a dynamic view of functions requires two or more varying quantities to be considered. In general, the graph covers a lot of information simultaneously in the context of chemical reactions. In fact, students tend to feel anxious when dealing with a graph, resulting in lower performance when asked equivalent questions using a graph instead of a table or algebraic equation (Rodriguez et al. 2019). In order for students to feel more confident in dealing with the mathematical representations and mapping contextual meaning onto these representations, they need to have a sophisticated conceptual understanding of functions. This paper explores how students engage with mathematical functions in a life sciences context, and how aspects of functional thinking might help to map contextual meaning onto mathematical representations.

1.2 Developing functional thinking

Functional thinking is “a way of thinking that is typical for dealing with functions” (Vollrath 1989). Three key aspects of functions are said to be typical: correspondence, covariation and the function as an object. The correspondence aspect emphasises that a function describes a relationship between two quantities, where each element of one quantity, e.g. the independent variable such as time, is mapped to an element of the other quantity, e.g., the dependent variable such as distance. Covariation focuses on how a change in the value of the independent variable affects changes in the value of the dependent variable. Viewing the function as a whole requires viewing the given functional relation as a new object that has its own properties and can be manipulated by operations. The correspondence aspect, which is mainly present in the definitions of functions, is the easiest for students to grasp. However, covariation is more important for understanding functional relations, and many difficulties students have can be explained by an inability to perceive the changing nature of functions (Malle 2000). Covariational reasoning is developmental and distinct levels of covariation can be achieved (Thompson and Carlson 2017). If someone can reason on a certain level, they are expected to be able to reason on all levels below that. Consequently, teaching the concept of function with a special focus on covariation should aim at the highest level which includes the ability to envision covariation smoothly and continuously.

Lichti investigated to what extent hands-on experiments or equivalent simulations with GeoGebra applets promote functional thinking (Lichti 2019). After the intervention, both groups showed significant learning gains in functional thinking with the simulation group making greater progress. Based on the students' written answers, the simulations promote reasoning based on covariation, while the hands-on group focused on the mapping of single values, i.e. correspondence. This is comprehensible due to the dynamic features of the GeoGebra applets, allowing for quick and easy manipulations of the independent variable to obtain values of the dependent variable instantaneously, thus enabling students to grasp the two covarying quantities more easily. Additionally, connections between different representations can be realised through subsidiary lines or colouring. The graph was found to be more efficient than a table for learning qualitative and quantitative functional thinking (Rolfes, Roth, and Schnotz 2022).

2 METHODOLOGY

2.1 Participants

The current study took place in the first semester of an undergraduate mathematics course at the School of Life Sciences of the University of Applied Sciences and Arts Northwestern Switzerland (FHNW). The course is compulsory for all undergraduates and therefore students from seven different fields of study take part. The learning environment was implemented during the first two weeks of the functions topic and consisted of consecutive exercises with corresponding GeoGebra applets. The material was provided through the MOODLE learning management system (LMS). After finishing an exercise, the students were asked to upload a file with their written answers. The analysed data refers to the second exercise of the learning environment. In total n= 89 students submitted their written answers of the second exercise.

2.2 Design of the learning environment

In developing the learning environment, the objectives were to identify a life sciences context 1) that is based on the concept of function and has the potential to promote conceptual knowledge and 2) that uses the representation of a graph with naturally arising varying quantities. These criteria were met by chemical kinetics, which has the potential to be beneficial for teaching the concept of functions (Rodriguez et al. 2019). As not all students choose a study direction that involves chemical kinetics, the learning environment should not require any prior knowledge of chemistry, but should leave some room for possible argumentation using prior chemistry knowledge.

With the development of GeoGebra applets, a chemical reaction was simulated and linked to a graph. The applets are therefore divided into two main parts, see Figure 1. The right part shows the developing graphs over time. The left part shows three bars representing the concentrations of the two reactants. The furthest left bar illustrates the cumulative concentration of both reactants, emphasising that 1) total concentration is constant over time and 2) the reaction could take place in a single vessel. The two adjacent bars show the concentration of each reactant separately. The height of the bars is related to the developing graphs. The dashed lines starting at the height of the bars and ending at the corresponding point in a two-dimensional coordinate system support the transfer from the simulated situation to the mathematical graph. To run the reaction, students can drag the *time* slider, which will simultaneously decrease concentration A and increase concentration B while the elapsed time is visualized by a thick black line on the horizontal axis. Below the coordinate system, check boxes allow the graph of each reactant to be shown or hidden.

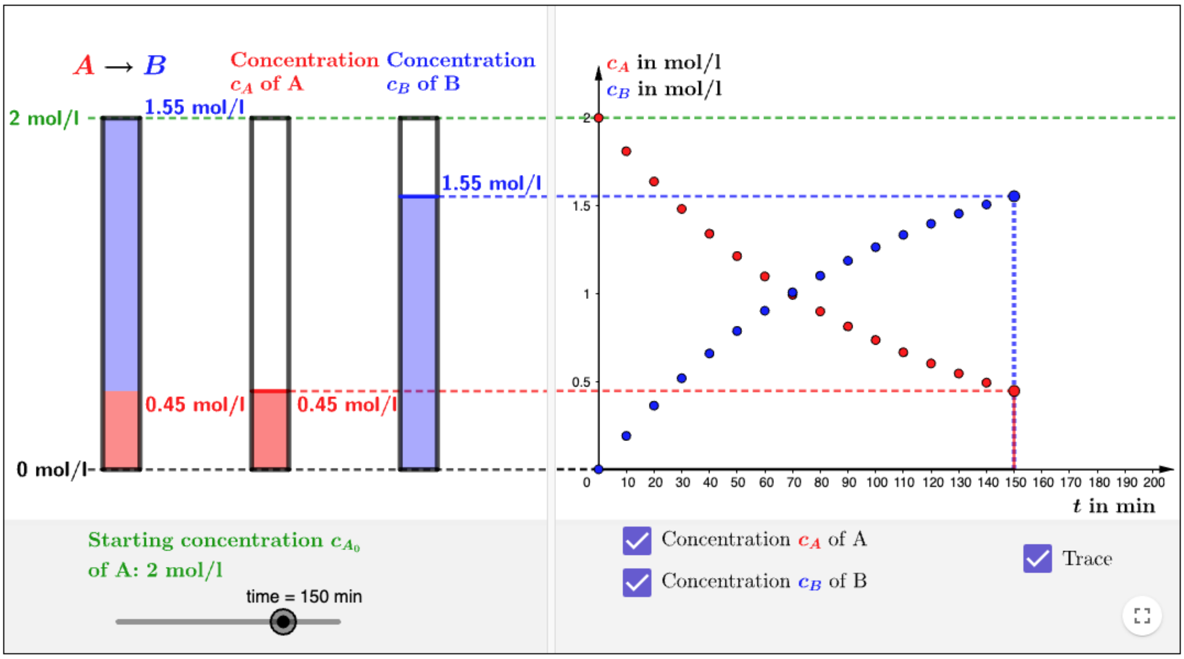

Fig. 1. Structure of the GeoGebra Applet

Activating the *trace* checkbox leaves all measured points, i.e. the potential curve, visible. With this applet students can easily carry out the chemical reaction and experience the connection to an evolving graph without doing any procedural tasks. The tasks in the exercises can therefore focus on describing and explaining the dynamic process of the chemical reaction in multiple representations and the translation between these representations. For example, in the second exercise the graph is introduced, and the first subtasks ask the students to explain how the elements of the bar chart (slider and height of the bars) are related to the moving point in the coordinate system, see Figure 2. Subsequent tasks require a comparison of the change in concentration during given time periods and an explanation why the change in concentration is continuously decreasing.

2.3 Data Analysis

To analyse the students' written answers, a content structuring qualitative analysis procedure was used (Kuckartz and Rädiker 2022). After the initial data overview, deductive main categories from literature were identified to code the material. The main categories consist of the three aspects of functional thinking, i.e. correspondence, covariation and object, as well as the different representations of functions used in the applet, i.e. graph, algebraic equation, bar chart and situational description. After the initial coding process, each main category is divided into smaller subcategories which show how students used the three aspects of functional thinking in the context of a chemical reaction. In addition, we can show how they were linked to different representations and how they might be helpful in the transition between representations. In particular, switching between a mathematical representation and the situational description is analysed. The analysed task consists of ten subtasks which have been coded separately. Multiple codes can be assigned per subtask or sentence, illustrated in Figure 2. Since the aspects of functional thinking can occur in combination with different representations the coded segments can overlap or intersect.

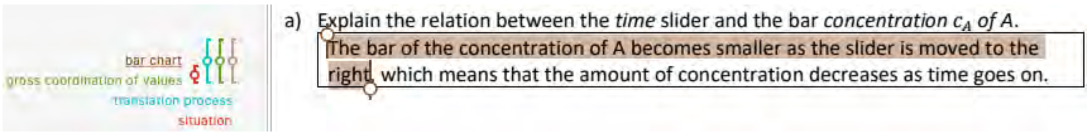

Fig. 2. Coding a student answer in MAXQDA

3 RESULTS

3.1 Subcategories of the aspects of functional thinking

The subcategories of the correspondence aspect are listed in Table 1. Due to difficulties in coding the students' responses without misinterpreting their thoughts, another category (mapping (vague)) has been added for answers that probably refer to the code "mapping". The last subcategory already indicates a dynamic view of the relationship between time and concentration and can be considered as a pre-category of covariation. As it explicitly focuses on the mapping of multiple time values to a concentration value, it still belongs to the correspondence aspect.

Table 1. Subcategories of the correspondence aspect

Subcategory	Description	Examples	Frequency
Mapping	A student writes that time is mapped to the concentration.	The red point shows the concentration of A at a certain point in time.	36
Mapping (vague)	A relationship between time and concentration is described. However, it is not clearly characterised as a mapping of the two quantities.	The height of the column indicates the concentration of A in the context of the minutes.	17
Starting concentration	The initial concentration of A (2 mol/l) or B (0 mol/l) at time t = 0 min is mentioned. Both quantities must be given.	During this reaction, at time t=0, c_A of A is at 2 mol/l and c_B at 2 mol/l.	12
Mapping (dynamic)	Time is seen as a variable quantity. Nevertheless, the process of mapping time onto concentration is described.	As you drag slider t, bar A indicates the corresponding concentration.	4

Comparing frequencies of the correspondence aspect subcategories with those of the covariation aspect, summarised in Table 2, it becomes clear that students more often describe features of the applets that show the dynamically changing quantities. Given the levels of covariational reasoning, only the level of gross coordination of values could be clearly identified. One could argue that the distance or secant line between adjacent points indicates argumentation at a higher level, i.e. chunky continuous covariation, but it is not clear whether students imagine going through all these values between adjacent points or not. So, another label was chosen.

Table 2. Subcategories of the covariation aspect

Subcategory	Description	Example	Frequency
Quantitative	Students calculate the absolute change in concentration or describe the procedure.	Look at the position of the previous point on the graph. Read the y-value. Do the same for the next point, then calculate the difference.	31
Gross coordination of values (see (Thompson and Carlson 2017))	Students write that concentration increases or decreases as time increases.	The concentration decreases as the time increases.	132
Distance of points	The change in time and concentration is registered by the distance between adjacent points.	The points in the coordinate system in period 1 have a greater difference than those in period 2.	32
Slope	The change in time and concentration is described by the slope at a single point or of a secant between adjacent points.	If one were to connect the two points for the two periods, the slope would be greater for the first period → greater change	53

Overall, the frequencies of all subcategories of the object aspect, summarized in Table 3, are higher than those of the correspondence aspect but lower than those of the covariation aspect. Some subcategories of the object aspect implicitly describe the change in time and concentration, i.e. flattening, declining change or monotonicity. They were assigned to the object aspect because they describe properties of an exponential function that are only accessible if considering the whole function.

Table 3. Subcategories of the object aspect

Subcategory	Description	Example	Frequency
Flattening	The flattening graph is described.	The red curve flattens with time.	70
Function type	A function type, i. e. linear, exponential, or Michael-Menten curve is given to describe or delimit the functional relationship.	An exponential decrease can be detected across the measuring points.	71
Declining change	The change in concentration is detected as decreasing with time.	The more time passes, the less the concentration decreases.	28
Monotonicity	The graph or concen-tration of A or B is considered to be decreasing or increasing over the entire time period.	The coordinates show the progress of c_A, which decreases more and more and c_B, which increases more and more.	58

Obviously, if a person captures the declining decrease in concentration over time they must somehow imagine two covarying quantities, i.e. covariation. The category function type was coded most often, which is understandable as students should already know about polynomial and exponential functions. It remains open, whether they recognise the shape of the graph or other properties to identify a particular function type.

3.2 Representations and translation processes between mathematical representations and situation descriptions

In this exercise “graph” was coded $n_{FG} = 529$ times and “bar chart” was coded $n_{BC} = 80$ times. One person tried to derive an algebraic equation and no one made a table. Since these representations are not provided in the applet, this was to be expected. Graph and bar chart were coded, when the term itself or parts of each representation were explicitly mentioned. The bar chart and the graph were mentioned together in 56 cases, most of which consist of the description that the height of the bar describing the concentration of A is equal to the height of the red dot in the coordination system. This does not necessarily address one of the aspects of functional thinking. On the other hand, when only the bar chart is mentioned, most answers address a subcategory of the covariation aspect. This suggests that students who recognise the dynamic relationship between time and concentration in the bar chart, and see that the height of the bar is equal to the height of the point, are likely to see the graph as describing two changing quantities. We also identified translations between the mathematical representations (bar chart, graph) and the situation. As the applet covers some terms that can be used to describe the chemical reaction, we could not code every response that contained the words concentration or time. Therefore, only those responses were coded that clearly attempted to map contextual meaning onto the mathematical representations. Currently, 73 responses show a translation between the situation and either the graph or the bar chart. A subcategory of covariation is addressed in most of them. An example is: “The height of the bar indicates the corresponding concentration. If the concentration decreases, the red point decreases accordingly”. In the first sentence, the person imagines that the bar represents the concentration of A, i.e. a translation from the bar chart to the situation has occurred. The next sentence describes the change in concentration and explains the movement of the point, i.e. a translation was made starting from the situation to explain the movement of the point. Another example illustrates the translation from the graph to a situation description: “The red point in the coordinate system moves to the bottom right when the slider is moved to the right, which means that the concentration decreases over time”. Here the person describes the movement of the point covariationally (subcategory: gross coordination of values) followed by a situation description of the change in concentration A.

4 SUMMARY

Although some students seemed to have difficulties explaining the functional relationship between time and concentration in written form, the bar chart simulation

firstly helped students to understand the dynamic relationship between time and concentration because they described the situation dynamically when referring only to the bar chart. Secondly, the height translation between the bar and the point in the coordinate system indicates that they relate the bar chart or the situational context to the graph and see the graph as a representation that describes a dynamic situation. Students tended to focus more on the covariation or object aspect than on the correspondence aspect, in line with literature (Vollrath 1989; Lichti 2019). Covariational reasoning (Thompson and Carlson 2017) was only present at the level of gross coordination of values, which could be due to the nature of the exercises, and it is possible that students were capable of higher level reasoning. Two reasons may explain the students' focus on the object aspect: 1) the representation of a graph is suitable for recognising the whole function and 2) students use prior knowledge from school to help them recognise function types as well as typical properties of functions. In the next course, accompanying video material may be recorded to give more insight into the use of the applets and allow a better distinction between the aspects of functional thinking.
Overall, the study suggests that dynamic applets have high potential for visualising covariation features of functions, but additional exercises could encourage more elaborate covariational reasoning, i.e., higher levels of covariational reasoning. In addition, preliminary results suggest that covariational reasoning supports translation processes involving a situation description. To support a covariational view in teaching the concept of function, computer-based simulations offer great potential because the underlying relationships are presented dynamically. Instructors then need to focus on the process that leads to an entire graph, rather than just on the result. Analysing the change in incremental intervals by looking at adjacent points or by anticipating values between points is important for thinking about different types of function that might be appropriate to describe the relationship of the underlying quantities.

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The Need for Interdisciplinarity: A Case on Employees' Perspectives

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ABSTRACT

The issue of interdisciplinarity contains disparate nodes of knowledge and practices, including a wealth of information concerning the potential and value of interdisciplinary work. In the context of companies that handle large-scale and complex tasks, interdisciplinarity takes on a real-life role since its presence and importance is readily observable and, as this paper shows, a conscious, deliberate, and highly valued aspect of innovation in companies. Academic literature on the issue of interdisciplinarity asserts that engineers in the future need a wealth of competences, including ability to collaborate in interdisciplinary teams. Aalborg University in Denmark has experimented with interdisciplinarity in various PBL contexts; the guiding research problem of this paper concerns how work practices call for interdisciplinary competence development. Through this perspective, we gain

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insight into how interdisciplinary competences are relevant for students at AAU as a competence that must be proactively developed.

The data set consists of nine interviews collected from a large Danish company. The interviews have been transcribed using Nvivo and coded according to the research problem. As the results of the qualitative data indicates, interdisciplinarity is not just an important competence for employees, but also a prerequisite for problem solving. Results indicate that interdisciplinarity is a competence that students must develop because interdisciplinarity is actively used for problem-solving in the types of jobs that engineering graduates will get in the future.

1 INTRODUCTION

The value of interdisciplinarity is well-documented. In the context of interdisciplinarity, there exists disparate nodes of knowledge and practices and these make the issue more far-reaching and complex. Interdisciplinary collaboration may manifest in several ways and will depend on a number of factors, including company culture, individuals' proclivities, and existing practices. When companies handle large-scale tasks, the ability (and willingness) to work in interdisciplinary teams becomes not just valuable – it becomes a requirement for success [1] [2].

It is valuable for researchers to focus on issues such as interdisciplinarity because it directly affects students – both during their time in various degree programmes, but also post-graduation in their first jobs. While contemporary teaching models, including problem-based learning, highlight interdisciplinarity as a key area, there remain important questions concerning the issue, not least regarding how interdisciplinarity is taught and understood [3] [4]. Furthermore, there exists a strong connection between disciplinarity (which remains crucial) and interdisciplinarity, but the ways in which these areas interact is complex and often opaque – for both educators and employees [5].

At Aalborg University in Denmark, several projects and initiatives have strived to introduce students to problem-based learning and interdisciplinary collaboration. These include projects such as AAU Megaprojects, LeadEng, and Hackathon [6] [7] [8] [9]. While this has yielded interesting results, certain limitations have also been revealed. Students found their participation interesting and highly relevant, but experienced interdisciplinary teamwork as challenging and to some extent inhibiting for problem solving. It became clear that transforming disciplinary competences to an interdisciplinary context is challenging for students and that more support and guidance is needed. With the aim of letting the different initiatives reflect reality, the projects have been multi-, inter- and transdisciplinary. The question remains, then, whether experiences gained from initiatives like LeadEng are reflected in interdisciplinary work practices in the industry. Once a person changes from being a student to being an employee, how do they use and think of interdisciplinarity? In this context, the specific *experiences* employees have at a given place of employment will significantly impact and alter their perception of interdisciplinarity (and collaboration generally). While day-to-day operations may rarely require substantial levels of interdisciplinary collaboration (e.g. operating a crane), departments that focus on innovation and other long-term perspectives rely on, and benefit from, interdisciplinarity to a high degree [1] [2]. Although employed at the same company, different departments may differ considerably with regards to culture, structure, understanding of key practices, and so on. With this in mind, this article is concerned with identifying the precise *understanding* of interdisciplinarity that employees articulate. Furthermore, we see most degree programmes as incorporating interdisciplinarity in various ways, but whether this corresponds positively to how interdisciplinarity is practiced in industry remains an open question. The guiding research question of this article is: What are employees' experiences with interdisciplinarity in practice and which competences are highlighted as important in this context?

2 METHODOLOGY

2.1 Research context

To gain insight into how employees understand interdisciplinarity in practice, this study is based on findings from a medium sized company in Denmark. Data has been collected through interviews with the company's innovation department, which specializes in innovation and (future) business models. The department is interdisciplinary in nature, housing both employees with engineering degrees and degrees from the humanities, working on internal and external projects.

2.2 Data collection

As this study is part of a larger project, this article acts as a pilot case providing an opportunity to explore understandings and experiences from the participants. The study is inductive in its approach, which provides an opportunity to follow interesting viewpoints among the participants that are not guided by predetermined topics of interest. The aim is to obtain insight into how interdisciplinarity is understood in practice.

The qualitative data was collected in January 2023 and consists of 9 interviews with employees with different educational backgrounds (see table 1). Each interview was collected individually and lasted approximately one hour. The interviews were semi-structured and provided the study with insight into how each employee experiences interdisciplinary collaboration – both in the context of internal and external projects. To minimize language barriers, the interviews were conducted in Danish. Any quotes have been translated by the authors.

Table 1. Educational backgrounds of the interviewed participants. All interviewees have been anonymized.

Background
Geography and Enviromental Management and Sustainability Science
Innovation Economy
Bachelor of Engineering

Master of Business Administration
History and Applied Philosophy
MSc in Organisation and Strategy
Economy and Political Science
Civil Engineering (Enviromental Management and Sustainability Science)
International Finance and Development Economics

The data has been transcribed using Nvivo and afterwards coded using thematic coding. This enables the study to become more focused, letting theory, or predetermined areas of interest, guide data collection. This study has been guided by the following themes: understandings of interdisciplinarity, competences relevant for interdisciplinarity, and the importance of interdisciplinarity in practice.

3 RESULTS

The data provides fascinating insight into the realities of working with innovation in a challenging and interdisciplinary context. The company itself, which manages both large logistical tasks while also attempting to innovate within research & development and be frontrunners, deliberately strives to have interdisciplinary teams solve complicated tasks. When asked specific questions about the realities of working in interdisciplinary teams and its effect on teamwork, it became clear that interdisciplinarity was not just a taken-for-granted aspect of working with large projects, but also a valued competence which simultaneously is a prerequisite for effective problem-solving. It also became clear that individual employees were able to drive projects forward as the onus is on them to make projects work. Furthermore, the employees are highly motivated and see their place of work as a boundary object which provides a common goal and common sense of purpose.

3.1 Work practice: what does interdisciplinarity mean to employees?

Concerning the importance of interdisciplinarity, it is relevant to unfold the interviewed employees' understandings of the term. The group of employees is generally synchronized as to how they understand interdisciplinarity.

Table 2. Different understandings of what interdisciplinarity means to employees

Themes	Explanation
Interdisciplinarity as different educational backgrounds.	Interdisciplinarity occurs when people with different educational backgrounds collaborate.
Interdisciplinarity as differences in both educational backgrounds and areas of responsibility.	Interdisciplinarity occurs not only when people with different educational backgrounds collaborate, but also

	concerns differences in functions and areas of responsibility.

Most interviewees define interdisciplinarity as being a group of people with different educational backgrounds working together to solve a common problem. One participant describes interdisciplinarity as a backpack of biases originating from both one's educational background but also one's upbringing. Everyone in the team brings in their expertise, and has different views of the project, collaboratively creating a common language. Two other interviewees expanded their understanding of the term: one sees interdisciplinary structures as collaboration among disciplinary backgrounds but also as collaboration across departments in a company. Here, interdisciplinarity is not only grounded in a disciplinary understanding of differences but also as differences between functions and areas of responsibility. Another agrees with this understanding and states that interdisciplinarity occurs when different fields of expertise or competence areas collaborate.

There exists an interesting (minor) disconnect between the employee's perspective on interdisciplinary collaboration and their view on management. For example, a participant observes that employees themselves facilitate and promote interdisciplinary collaboration, while management work in fixed and inflexible silos. Seemingly, autonomy is a prerequisite for productive interdisciplinary work and a common goal, or boundary object, is a central component in this regard as well. One participant noted that this is one reason why highly educated candidates are hired; they are self-motivated and able to progress towards their goals with little interference or (micro) management needed.

Possessing a goal-oriented mindset is a recurring theme that interviewees highlight. One participant defines interdisciplinarity as collaboration across multiple educational backgrounds, but also notes that they must, "solve a project together," and, "each have their own perspective concerning what must be delivered." Furthermore, it is mentioned that being aware of one's own and others' educational backgrounds is important, but it is equally important to be aware of one's own competence-related limitations. Typically, working in interdisciplinary teams provides insight into people's strengths and weaknesses, which turns into an advantage as employees are able to support each other and fill knowledge gaps. One participant stated that, "If I hadn't been aware of [my own limitations], then I could have spent a lot of time on something I don't really know anything about and then made poor decisions which might set back my time schedule." This is interesting because it highlights that depth of disciplinary knowledge is central, but a group's potential develops positively if a multitude of educational backgrounds all contribute – even backgrounds whose potential contributions may not at first be readily apparent.

Several interviewees also indicated that there is an unspoken (or tacit) component to interdisciplinary work. To a large extent this is related to generic competences. A participant notes that many important aspects of successful interdisciplinary collaboration cannot be put into a formula. “Things happen around [an interdisciplinary] table that you cannot reduce to a formula, especially concerning mutual respect and other people’s cultural or work-related backgrounds.” Learning to have confidence in other’s contributions, and trusting that these are worthwhile, is a valued skill that develops as employees gain experience with interdisciplinary collaboration.

3.2 The importance of (inter)disciplinary competences

When asking the interviewees about their experiences with interdisciplinarity in regard to the importance of disciplinary competences, a tendency appears in the answers. Several of the employees articulate the importance of disciplinary competences in contrast to the more personal traits such as openness, curiosity, and engagement.

Table 3. Different understandings of the balance between disciplinary competences and personal traits

Themes	Explanation
Personal traits as a gateway for getting disciplinary competences into play.	Personal traits become necessary for establishing interdisciplinary teamwork and to get disciplinary competences into play.
Disciplinary competences and personal traits – you cannot say one without the other.	Personal traits and disciplinary competences as equally important.
Personal traits as more important than disciplinary competences.	Personal traits as more important than disciplinary competences.

One participant mentioned the importance of disciplinary competences in the team, but also stated that in the beginning your personal traits play a significant role in establishing the team. Another participant sees personal traits as a gateway for getting disciplinary competences into play. The participant stated that, “It is no use that you are super deep in your disciplinary knowledge if you are not able to be part of a team”. Another participant asserted that 45% importance is placed on disciplinary competences, and 55% importance is placed on personality, and furthermore stated the importance of being able to fit into the team. However, it is also stressed that situations differ, and the above distribution may be inaccurate; disciplinary depth may weigh more heavily concerning certain types of problems. A third participant agreed that personal traits are important for interdisciplinary teamwork and sees the influence of personal traits as an important factor for creating fruitful dynamics in a team. “Personally, I think personal traits are really important. Of course, disciplinary knowledge is important but overall, I would say that personality is important, and there is no doubt […] that when you can give each other a hug or a pat on the back, you can also more easily […] push for a task to be done [...]”. A central goal is creating a space where everyone feels comfortable, as well as creating an agenda that all group members identify with. This becomes part of creating a common language within interdisciplinary groups.

The nature of interdisciplinary competences is complex, and participants focused on various areas. For example, one participant stressed that patience is surprisingly important and something that can be learned (by necessity). “When you have worked in different places, as I have, then you learn that patience is a virtue. You might think that you have reached your limit, but you never have.” Cultural awareness and practices, it seems, factor highly and the same participant focused on this topic a lot. It is furthermore noted that cultural context matters more than some might think: “It [aware of others’ abilities] is something we do well in Denmark; a cleaning lady may provide good ideas as easily as anyone else. We understand that everyone has an opinion and can contribute. Sometimes we mustn’t think that just because we have a particular degree then we’re smart.” Another participant touches on the same topic but focused on the importance of making people function together on an interpersonal level before they can collaborate on a professional level. “My experience is that if you can get people to play together, then you’re also creating trust and relations which you can later build upon further. That works really well.” There seems to exist a relationship between personal traits and interdisciplinarity. The starting point remains the discipline and educational background itself, but in order to make complex interdisciplinary collaboration really *work*, certain personal traits are necessary. This, as it turns out, also significantly and positively influences problem-solving potential and continued learning for individual employees.

3.3 Personal traits and interdisciplinarity

While disciplinary knowledge is required and valued, certain personal traits were contributing factors that significantly influence (interdisciplinary) collaboration. Speaking of a colleague with a different professional background, one participant articulated how their colleague showed engagement and became (more) valuable. “[h]e really has developed [professionally]; he has acquired new knowledge, was curious, has learned, observed, and delved into sustainability […] I did not have the same experience. In the beginning, it [collaborating] was difficult because we didn’t know each other.” Participants generally reported that feeling a sense of connection or common purpose was crucial for interdisciplinary collaboration. While it is possible to collaborate with strangers with whom one feels dissimilar, the consequences of positive relations prior to collaboration are profound. Other participants expressed the same views: “It is important that people accept each other in these roles, and that they want what’s best for each other”. In the same vein, showing a degree of openness and curiosity was clearly beneficial, but participants also articulated the importance of being aware of one’s own disciplinary limits and, therefore, the need to listen and learn. “It is important to contribute with whatever disciplinary knowledge one has. People with the same background talk the same language. It is possible to learn a lot via the experiences other disciplines have, and that’s something I find to have strengthened collaboration […] by being curious about what the other disciplines deal with, and curious about how what I contribute influences the things they work with." It is quite telling that, when asked if situations exist where interdisciplinary collaboration does not make sense, participants unequivocally (and usually very fast) said no. "No, not at all." However, as noted earlier, it is in this context worthwhile to note that certain departments may benefit more from interdisciplinary collaboration than others.

Ultimately it became clear that personal traits are important in order to make interdisciplinary collaboration function, but articulating precisely how this happens, or which specific competences are necessary, can be difficult. Specific and expected competences were recurring, such as respect, ability to listen, and openness, but participants had some difficulty expressing how exactly this manifested in specific situations. Personality, then, plays a big role but experience with interdisciplinary and other educational backgrounds may enable employees (or students) to broaden their horizons. Understanding that problems rarely only have one single possible solution is the first step in acknowledging that other disciplines may be able to contribute to innovative and unexpected solutions that are also viable.

4 SUMMARY AND ACKNOWLEDGMENTS

The findings have proven valuable and provided productive insight into interdisciplinarity. While the issue of interdisciplinarity is multifaceted and remains context-dependent and complex, our qualitative analysis nevertheless points to certain patterns. For example, the benefits of interdisciplinarity are strongly supported by the participants – regardless of their educational background. The importance of personal traits has been stressed by all participants, and there is strong potential for further research that might map the precise nature of these traits. The outcome of this article provides a starting point that clearly points towards interdisciplinarity being valuable for certain types of jobs, particularly ones that focus on innovation and long-term projects. Consequently, university curricula might be adjusted to better prepare students for what seems to be inevitable interdisciplinary collaboration. In this regard, we also see strong potential for further research; while the current research has tapped into the realities of one particular company, more data collected from other companies may provide new or differing insights as other companies will necessarily exhibit other work cultures, other ways of structuring departments (and consequently collaboration), and other ways of understanding and conceptualizing the issue of interdisciplinarity.

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A CULTURAL-HISTORICAL ACTIVITY THEORY APPROACH TO STUDYING THE DEVELOPMENT OF STUDENTS' DIGITAL AGENCY IN HIGHER EDUCATION

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ABSTRACT

Researching classroom practice requires theoretical resources that can explain the variety inherent in such an activity as well as the dynamic nature of classroom practice. Cultural-Historical Activity Theory (CHAT) offers the possibility of accounts of social, cultural, and historical aspects of the context and of how students adapt and transform in these contexts. This conceptual paper engages with the relevance and utility of CHAT for researching student practices in a course as an activity system. It draws on

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part of a Ph.D. research study that explores first-year engineering students' access and engagement with technological resources for learning. A key concept in the study is the development of the ability to control and adapt to technology, known as digital agency. The research question addressed in this paper is *"How does CHAT reliably build theory of the complexity inherent in the development of digital agency among first-year engineering students learning at a university?"* Some of the challenges in the application of CHAT for researching in this context are identified, such as describing practice as an activity system and identifying the object of the activity system. In addition, the value of CHAT for such studies is explained including the contribution it makes in the identification of contradictions and tensions that cause change and development in the activity system. These findings offer insight as to the usefulness of CHAT for engineering educators and scholars understanding their practice or researching learning and teaching in the classroom.

1 INTRODUCTION

1.1 Context

Higher education institutions have migrated from traditional approaches to teaching and learning without digital technologies to the ubiquitous use of information and communication technologies for teaching and learning. A review of the literature on the 20-year journey of technology-enhanced learning in South African universities reveals that these institutions have transitioned from relatively subpar ICT infrastructure and education provision to cloud-based ICT infrastructure with unlimited educational resources that are freely, openly, and simply accessible both within and outside the institution (Ng'ambi et al. 2016). As universities develop ICT infrastructure for learning, some students still face challenges in adopting and adapting to technology due to the high levels of inequality that have their roots in the apartheid era. Oyedemi and Mogano (2018) established in their study that 73 percent of students did not have access to computers at their high schools and 82 percent of students from rural high schools did not have computer access or internet at their schools. As such, many students enter university with varying levels of digital literacy, and digital skills. Others lack hardware devices, internet services, and access to digital technologies for learning. Another study into the use of technology in teaching and learning in South Africa found that students' social practices and learning through digital media lacked opportunities and experience with digital technologies (Czerniewicz & Brown 2013). It was reported in this study that students had hardly used a computer prior to university and did not have easy access to technology off campus. The persistence of the digital divide in the country therefore presents challenges to both students and educators.

Ragnedda and Muschert (2017) described three levels of the digital divide, including physical access to the internet, different uses of the internet, and social and tangible benefits accrued from differentiated uses of the internet. First, there is a divide between those who can and cannot access the Internet; second, there is a divide regarding motivation, aptitude, and purpose of use; and, thirdly, there is a divide with respect to the social, cultural, economic, personal, and political benefits that can be gained online. The latter demonstrates that there are socio-technological disparities between persons from different backgrounds that impact on their opportunities and capacities to translate digital involvement into benefits while avoiding the harm that may result from using ICTs (Ragnedda & Muschert 2017). This contributes to limitations in the development of digital skills, competence, and literacies among some students.

First-year engineering students require engagement with ICT for learning in a range of courses. Differential access and preparedness for technology therefore presents challenges for both students and course lecturers. How students develop their digital capabilities, resolve contradictions that may exist, and transform their social conditions in the process, is of interest in this study and informed the choice of Cultural-Historical Activity Theory (CHAT) as appropriate for conceptual framing. Contradictions are tensions or conflicts between and within activity systems that are potential sources of change and development and are used for empirical research (Engeström 2001).

1.2 Digital agency

The term digital agency was first used at the Fifth International Summit on Information and Communication Technology in Education in 2017 where it was defined as the individual's ability to control and adapt to a digital world (Passey et al. 2018). Since then, other definitions have emerged. For example, Goriss-Hunter et al. (2022) defined digital agency as the level of autonomy that a student experiences when digital technology is used in the classroom. Digital agency is regarded as a subset of student agency and some scholars still describe it as student agency in a digital learning environment. It has been argued that academic achievement and how students feel about their learning experiences in a digitally mediated environment are significantly impacted by student agency (Luo et al. 2019).

As research on digital agency emerges, it has the potential to inform interventions and influence engineering students' digital learning environments and learning skills (Klemenčič 2017). Digital technologies have the potential to transform underprepared students in the use of technology to become competent others who can teach their fellow students how technology is used for learning. It is argued that in education, digital technologies affect human people relationally, culturally, and technologically suggesting that the framework of agency should consist of critical domains to student agency in digital contexts (Stenalt 2021).

1.3 Cultural Historical Activity Theory (CHAT)

CHAT has developed and evolved as an interdisciplinary theory over more than 100 years (Fenwick et al 2011). The principles of CHAT were first drawn from the works of Vygotsky, Luria, and Leontiev (Engeström 2001), and is a theory that has widely been applied in educational research in a variety of contexts. From CHAT's earliest days, it elucidated relations, mediation, human learning and development proceeds using direct experimental and non-experimental empirical research (Fenwick et al. 2011). For explaining learning and development, CHAT not only focuses on the role of people's social relations but also the use of tools/artefacts over time. This represents a departure from the theories of learning and development as a purely cognitive process.

Fenwick et al. 2011 contend that CHAT is frequently used in naturalistic and qualitative educational research. CHAT provides a knowledge of the historical approach to activity, considering the history of mediating objects, learning environments, technology, and many more. A variety of case studies and comparative studies employing CHAT in settings such as classrooms have also been published.

In recent years, CHAT has frequently been used in interventionist research approaches on educational environments, including change laboratories (Sannino et al. 2016). Mukute (2009), for example, used CHAT to identify and analyse inconsistencies; model and implement solutions in permaculture learning and practice at one school and its community in Zimbabwe. CHAT is also useful in educational research where curriculum, programmes, and organizational transformation are of particular interest (Fenwick et al. 2011).

CHAT has been found to be useful in expounding the complex systems involved in computer human interaction studies in the education arena (Kaptelinin & Nardi 2018). For example, CHAT was used to demonstrate how instructors use technology to mediate the teaching and learning of a subject in primary school (Hardman 2005a). Similarly, the study was broadened to show how CHAT provided a framework for South African technology research (Hardman 2005b). CHAT was also used to investigate pedagogical variations in teaching computers in mathematics classes (Hardman 2015). The study drew from CHAT to understand pedagogical modes emerging out of teaching with technology. Batiibwe (2019) conducted a literature review on the application of CHAT to understand how emerging technologies can mediate learning and instruction in a mathematics classroom. She supported the idea of the classroom as an activity system and found the mediation tool in CHAT to be effective.

The concept of social change is intertwined with CHAT and aims to comprehend the world not as it is, but as it evolves. This makes CHAT relevant for studying agency in the educational space. Hopwood (2022) examined three approaches to agency when using CHAT, namely, transformative activist stance, transformative agency by double stimulation, and relational agency. Despite overlapping underpinnings and apparent commonalities in dialectics, mediation, motives, and practice, they identified significant variances. Bringing these distinctions to light revealed what each approach in CHAT has to offer as well as the subtleties that set them apart. CHAT also conceptualises agency as mediation development where change happens due to unavoidable contradictions and tensions inherent in the activity system. Development is therefore understood as a process of becoming a subject capable of agency, that is, able to contribute, influence and change the environment and the social as well as material circumstances (Rainio 2010).

This paper draws on part of a Ph.D. research study that explores how first-year engineering students access technological resources for learning. A key concept in this study is the development of their digital agency. The objective of the study is to show how CHAT reliably builds theory describing the complexity inherent in the development of digital agency among first-year engineering students learning at a university.

2 METHODOLOGY

2.1 Data collection

An ethnographic approach to data collection was employed in the Mechatronics Engineering class. After obtaining ethics approval, observations and interviews were conducted. Observations of the students during engineering drawing classroom learning was undertaken for three hours per week over eight weeks. The researcher observed events and patterns which appeared to account for the agentic behaviour among students as they used digital technologies. Following the observations, nine students were identified for one-on-one interviews through purposeful sampling. The interview questions were revised repeatedly for internal consistency. The interviewee explained the questions to the students for reproducibility. Each interview lasted approximately one hour. Indicators of the development of digital agency were identified in literature. They included students' autonomous use of technology, breaking away from a frame of action, visualizing new possibilities, transforming disturbances encountered collectively and ability to collaborate with others as they learnt the subject. The data were in the form of field notes, interview transcripts, videos, and audio of recorded lectures.

2.2 Data analysis

In the data analysis phase, both inductive and deductive coding were employed to analyse the observations and interview data through thematic analysis. All nine audio recordings from the one-on-one interviews were transcribed, and the transcripts were carefully edited and verified for accuracy. To protect the privacy of the interviewees, pseudonyms were used to anonymize their identities.

Interview transcripts and field notes were imported for analysis into NVivo Release 1.7, a qualitative data analysis software, for first level coding. In vivo statements were extracted and analysed for concepts that are related to the research question. The concepts were then categorised into themes based on CHAT tenets categories, namely, subject, object, division of labour, community, rules, outcome and mediating artifacts. After categorising the concepts into themes, the activity systems within the data were examined, and contradictions present were identified. These contradictions were further scrutinized to determine their contribution to the development of digital agency among engineering students. This analysis aimed to explore how the identified contradictions influenced the students' ability to exercise control and adapt to digital technologies in their academic activities.

3 RESULTS AND DISCUSSION

To understand digital agency development and its possible consequences, the activity system and its tenets were identified and analysed from the data. The CHAT activity system was used to delineate the engineering classroom activities into the tenets of subject, mediating artifacts, object, rules, community, and division of labour. Although the classroom learning practice had a number of subsystems, only the main activity system is presented in this paper. A second-generation CHAT activity system that describes the interactions among the tenets is shown in Fig. 1. The activity system was used as the unit of analysis.

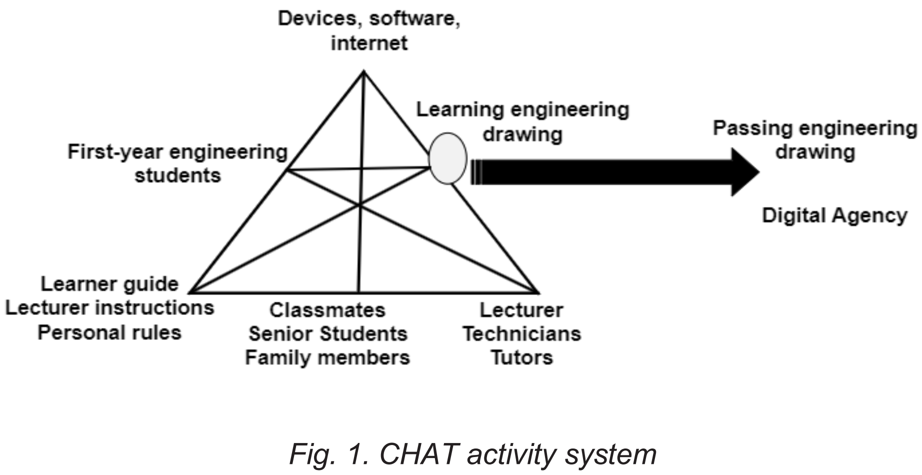

Fig. 1. CHAT activity system

In this study, the engineering students are the subjects involved in the achievement of the object. The object is important because it is the moving target in an activity system (Engeström 2001). The object in this case is learning engineering drawing including theory and practicals, mediated by cultural mediating artifacts (devices, software and the internet) embedded within a social context. The community is the broader social context in which this system operates. In this case there are senior students, family members and classmates. For example, classmates assist one another in learning the software and carrying out homework tasks. Learning software, devices and the internet as well as learning the subject, constantly drove the activity systems guided by the rules. The division of labour consisted of people who assisted the students as they learnt the subject. The lecturer was a resource as he taught and assessed the students online, face-to-face and via pre-recorded videos. By studying the activity system, the researcher could identify the interactions that first-year engineering students had to negotiate, as well as the tensions and contradictions in these interactions.

3.1 Contradictions

The CHAT analysis showed that there are two significant sets of contradictions to the development of digital agency as shown in the activity system (Fig. 2.); the primary and the secondary contradictions. The primary contradictions were identified within the mediating artifacts: device, software and the internet that are used for learning in the engineering course. The secondary contradictions were identified between the subject and the object, subject and mediating artifacts as well as between the subject and the division of labour.

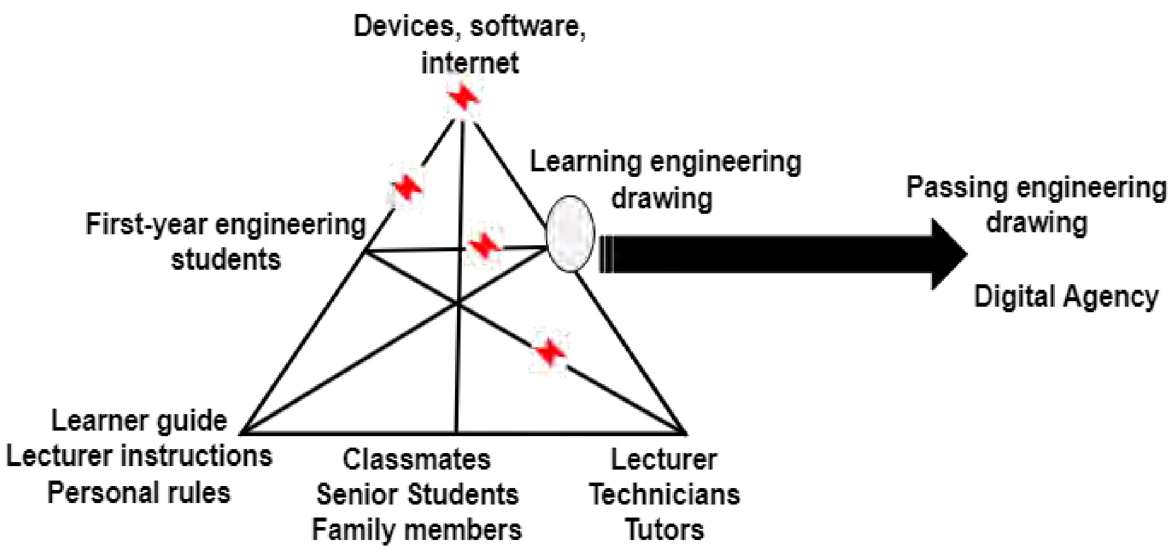

Fig. 2. Tensions in activity system

The type of contradictions and their locations are described in Table 1. In resolving these challenges, students showed attributes of digital agency. For instance, in the context of this study, engineering students were required to secure funding and purchase additional Random-Access Memory (RAM) to enhance compatibility with software applications such as SolidWorks and AutoCAD. In order to enhance the two-step verification sign-in process for Blackboard, students needed to ensure their phones were charged to authorize the login. Alternatively, some students opted to work remotely from their residences to overcome challenges posed by non-portable desktop computers and software versions that differed from those available on campus.

Table 1. Primary and secondary contradictions

Contradictions/ Location	**Examples**
Primary Within mediating artifacts	RAM inadequacy in laptops. LMS reported to be redundant, difficult to use, had sign-in issues, needed two-step verification, and had an incompatible application for cell phones. Desktop computers were not portable, updates were incompatible. Tablets and cell phones were not compatible with the software.
Secondary Between subject and mediating artifacts Between students and division of labour Between students and object	First year engineering students had no access to devices like laptops and had no knowledge of software and applications. Slow/no wi-fi connection. Different software versions. Transmission-oriented teaching. Power failure issues, and long online lectures.

The prevailing power failure issues are culturally and historically explained as they date back to the apartheid era and lack of investment and corruption in the democratic era. Despite the power outages, first-year engineering students exercised agency by discovering ways to complete engineering drawing tasks using software, devices, and the internet. Even during power outages, some students used their recharged laptop batteries to do engineering drawing tasks for a few hours. Others who did not have access to laptop computers worked on non-digital assignments before returning to drawing tasks once power was restored.

3.2 CHAT's contribution

In this study, there was a classroom learning environment where the lecturer instructed the first-year engineering students using digital technology. CHAT was used to frame the system in context, including social, cultural, and economic influences over time. The rules that students observed whilst interacting with the lecturer were historically based and culturally negotiated. Numerous circumstances beyond both the lecturer and the engineering student's power to modify them individually enabled and constrained each party's agency, that is, the acts they performed in relation to each other. A variety of other individuals, such as classmates and senior students, mediated the interactions for this particular subject.

Cultural-Historical Activity Theory was applied in this study with reference to the specific meaning of each word in its name. The term cultural in this instance referred to the idea that first-year engineering students were enculturated, and that everything they did was influenced by and drawn from their cultural resources and ideals (Foot 2014). The terms historical and cultural were used in combination to denote the idea that because cultures are rooted in histories and change through time, analyses of what the students did at any given time was understood in the context of those histories. To communicate its situatedness, the term activity, which referred to what students did collectively, had undergone cultural and historical modifications. In addition, CHAT encapsulated the conceptual framework for comprehending and explaining students' activity that led to development of digital agency.

Students created, employed, and adapted to digital technologies of various kinds to learn and communicate (Vygotsky 1978). The activity system where students learnt engineering drawing was constantly changing through learning actions in response to CHAT's systemic contradictions that allowed a multifaceted analysis of the complex practice in the hybrid classroom. The contradictions and tensions in the activity system which are historically explained, caused students to find alternatives to overcome them thereby developing their digital agency.

3.3 Complexities of CHAT

Using CHAT as a theoretical framework and tool to build theory presents complexities. One challenge is the difficulty in determining the *object* and the perspective from which it should be named. There is ongoing debate about who should define the *object* and how it guides the other components of the system. In the specific activity system depicted in Fig1, the object was defined by the researcher rather than through collaborative efforts by a group. The participants could have defined the object differently. Conceptualising the course as an activity rather than selecting a particular practical or task also increased the complexity of the application of CHAT.

The activity system depicted in Fig.1 served as the main focus of analysis, emphasizing a collective perspective rather than individual actors. This approach, as suggested by Engeström (2001), highlighted the limitations of CHAT in adequately addressing the individual experiences with digital technologies. By zooming in and examining each student's unique responses to contradictions related to technology, a deeper understanding of their development of digital agency could be gained. This finer-grained analysis would provide valuable insights into how students navigate and adapt to digital technologies within the context of the activity system.

4 SUMMARY

In summary, CHAT framework proved to be a valuable tool for investigating the development of digital agency in educational settings. CHAT offered a comprehensive understanding of this developmental process by taking into account both the social and material aspects and their interplay within the classroom. The outcomes of this study shed light on the applicability of CHAT for engineering educators and researchers who aim to enhance their understanding of their own teaching practices or explore the dynamics of learning and teaching in the classroom.

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GOING BEYOND INTENTIONS: A METHODOLOGY FOR ASSESSING ENTREPRENEURIAL ACTIVITY AMONG ENGINEERING EDUCATION ALUMNI

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Keywords: *Entrepreneurship, Innovation, Engineering Education, Generative Pretrained Transformer (GPT), Artificial Intelligence (AI), Machine Learning (ML), Program evaluation*

ABSTRACT

This research paper proposes a novel methodology for evaluating entrepreneurial activity among engineering education alumni using their public CVs as our main source of information. The objective is to go beyond measuring entrepreneurship intentions or mindset through surveys, and instead analyse actual career data to assess the impact of entrepreneurship education. The study utilises shared user data and employs GPT (Generative Pretrained Transformer) models to infer entrepreneurial activity that extends beyond job titles, delving into the specific responsibilities and achievements associated with each position.

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The analysis shows that the proposed methodology, which uses context enriching to enhance model accuracy, effectively identifies instances of entrepreneurial activity among CVs profiles data. This approach provides a way to evaluate the effectiveness of entrepreneurship and innovation courses. Combining the insights gained through the proposed method with internal data sources would enable institutions to conduct a comprehensive evaluation of program impact on alumni career paths.

The study underscores the potential of AI models to facilitate the collection and analysis of data that has traditionally been challenging to access. Moreover, the research highlights the importance of evaluating the long-term impact of entrepreneurship education on alumni career trajectories, a key factor in addressing the growing field of engineering education. Ultimately, this study contributes to the academic discourse on entrepreneurship education by offering a novel approach for assessing the impact of such programs on alumni outcomes, thus enabling institutions to make data-driven decisions to improve program offerings.

1 INTRODUCTION

Entrepreneurship and innovation have become increasingly vital in engineering education, as they are fundamental skills for students to develop in order to succeed in the global economy. Numerous higher education institutions have implemented entrepreneurship programs to provide students with the necessary knowledge and skills to launch their own businesses or innovate within existing organisations. However, evaluating the effectiveness of these programs has been challenging, as existing methods often rely on self-reported data from surveys, which may not accurately reflect actual entrepreneurial activity. This research paper proposes a novel methodology for assessing entrepreneurial activity among engineering education alumni by analysing their public CVs. The methodology aims to move beyond measuring entrepreneurship intentions or mindset and instead analyse actual career data to assess the impact of entrepreneurship education. The study utilises shared user data and employs GPT (Generative Pretrained Transformer) models to infer entrepreneurial activity that extends beyond job titles, delving into the specific responsibilities and achievements associated with each position.

Although the research question of the overall project could potentially be: "How can entrepreneurship and innovation be effectively promoted among engineering students, and how can the impact of these efforts on their career trajectories be measured using AI and machine learning?", this paper aims to solely describe the methodology and present a first set of preliminary results. Therefore, the research question adjusted to the scope of this paper would be: "Is it possible to extract useful information about the entrepreneurship and innovation activities of engineering education alumni using AI with their public CVs?"

1.1 Literature review

Within the field of artificial intelligence research, one particular type of transformer has garnered significant attention due to its text-generating capabilities. This popularity can be largely attributed to the groundbreaking work of OpenAI and its ChatGPT platform. Specifically, the GPT models, including GPT, GPT-2 and GPT-3, have become widely recognized as standard transformer architectures trained using a language model objective. While their primary success has been in natural language generation, these models have also demonstrated impressive performance in other tasks (Radford et al. 2018; 2019; Brown et al. 2020). However, the field of AI research is constantly evolving, with ongoing research and publications exploring the potential applications of GPT-4 and future versions, as well as the associated concerns (Liu et al. 2023).

The field of education is no exception to this trend, with growing literature on the use cases and applications of LLMs (Large Language Models) in general, and GPT in particular, for educational purposes. Previous work highlights the advantages of this new technology in engineering education, which can be extrapolated to the education realm in general. These recommendations aim to embrace the technology to reduce manual work, contribute to and use open sourced models, and shift to a more student-centred approach, while understanding the current limitations of the available models and establishing ground rules and standards for their fair use for both students and practitioners (Yan et al. 2023; Qadir 2023).

Building on these recommendations, this study aims to leverage this new technology to provide a new approach for evaluating entrepreneurship or innovation programs within engineering education. Past literature contains existing examples of evaluation methods for this type of program, which can be grouped into three categories: (1) surveys to students upon program completion to assess entrepreneurial skills (Bellotti et al. 2013; Bilén et al. 2005; Wang and Kleppe 2001; Ohland et al. 2004); (2) surveys to evaluate entrepreneurial intentions (Souitaris, Zerbinati, and Al-Laham 2007; Joseph 2013); and (3) alternative assessment methods such as qualitative interviews with students upon program completion (Creed, Suuberg, and Crawford 2002). However, to the best of our knowledge, no existing method incorporates AI techniques as a supplementary means of program evaluation. Therefore, this study aims to introduce an AI-based approach to augment the existing evaluation methods for entrepreneurship and innovation programs in engineering education.

2 METHODOLOGY

In this section, we present the proposed methodology for assessing entrepreneurial activity among engineering education alumni. The methodology involves a multi-step process as depicted in Fig. 1.

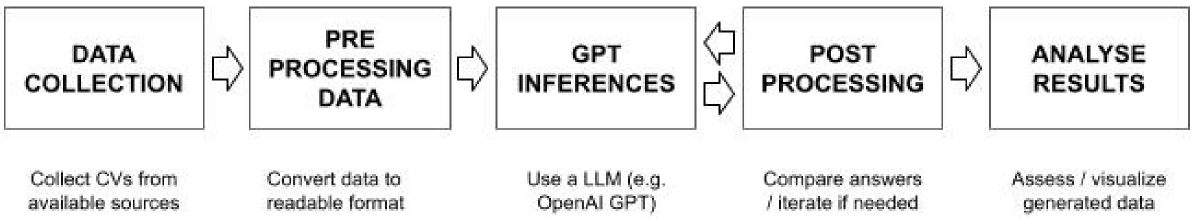

Fig. 1. Methodology flowchart.

2.1 Data collection and preprocessing

The methodology of the present study involves the collection and evaluation of curriculum vitae (CVs) from a sample of engineering education alumni. However, due to the lack of standardisation in the format and template of the CVs, it was necessary to employ a dedicated group named *"Xarxa Telecos BCN - Associació Oficial d'Alumni de la UPC ETSETB* LinkedIn to obtain 200 CVs in PDF format. This group, with approximately 2,000+ members, aims to gather Technical University of Catalonia (UPC) - Telecos BCN alumni. Therefore, we decided to review approximately ~10% of randomly selected users to conduct this initial experiment since the expectation is that members in this group have graduated in engineering. Thus, we can run this first experiment with them to test this methodology. Please note that the CV generation was done manually, so no scraping technique or whatsoever was involved. We directly had access to these profiles as we are part of the same group and share our personal information as well.

It should be noted that while the PDF files have the same format in this study, the proposed methodology is not limited to a specific template and would work equally well with different types of CVs. This is because the methodology uses GPTs to extract information from the content of the CVs, irrespective of the formatting one can find in the real world as seen in Fig. 2. The pre-processing stage involves converting the PDF files into plain text that can be used as input for GPT inference. Additionally, data cleansing techniques are applied to eliminate special characters and ensure that the GPT model can accurately interpret the data.

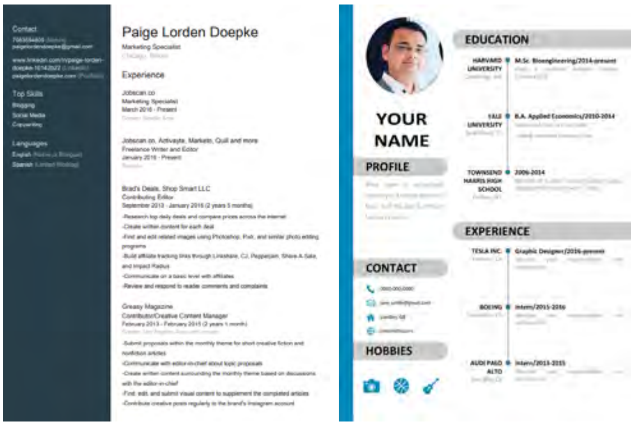

Fig. 2. Potential problem for just parsing information from different CV templates.

2.2 GPT Inferences and postprocessing

This research employs GPT models to analyse entrepreneurial activity beyond job titles, exploring the specific responsibilities and accomplishments associated with each role. To accomplish this task, the study utilised the API (Application Programming Interface) from OpenAI, specifically their commercial model *"gpt-3.5-turbo"*. When employing such models, it is crucial to refine the prompt to ensure that the model comprehends the task requested. As a result, the prompt underwent initial trial and error modifications to obtain the expected results. In this study, a prompt was constructed utilising a chat format by concatenating various text chunks:

- Background information: *“You are about to analyse a CV…”*
- CV information: CV content in txt format
- Information requested: *“From the previous CV I need you to confirm the following information: 1) Full name of the person…”*

In order to facilitate the extraction of data from the responses generated by the GPT model, we employed a strategy whereby the desired answer was specified within brackets, as exemplified by the prompt: *“What is the name of the person? in your* *reply put the full name between brackets []"*. Notwithstanding the clarity of these instructions, it is possible that the desired outcome may not be achieved even when the correct answer is correctly bracketed. The probabilistic nature of the GPT model implies that the responses generated by the model will vary from one instance to another, even when the same prompt is used. In Fig. 3, we present an illustrative example of this phenomenon, where four duplicate CVs were subjected to analysis, yielding different outcomes: results that are coloured red indicate that they are not valid due to missing information or errors, and require repeating the GPT inference; orange-coloured results denote that the generated responses differed from the same prompt, and green-coloured results signify that the responses were identical across both inferences.The main takeaway is that, through this iterative process, the AI model used in this particular case eventually transforms "N/A" into actual values and validates initially uncertain information inferred from the CV after iterating again.

ID	Full_Name	Current_Role	Current_Comp	Education_UPC	Last_Year	Business_Man	Entrepreneur	Entrepreneur_Description
CV_000001	[DTS]	[Purchasing Engineer]	[DENSO]	[M.D. in Organization ...]	[1997-1998]	[N/A]	[Freelance Engineer]	[He worked as a freelance...]
CV_000001	[DTS]	[Purchasing Engineer]	[DENSO]	[M.D. in Organization ...]	[1998]	[N/A]	[Freelance Engineer]	[He worked as a Freelance Engineer...]
CV_000002	[XS]	[Project Manager D... T... Global Business Iberia]	[D... T...]	[Ingeniero Superior Telecomunicaciones ...]	[1992]	[PMP - Project Management]	[N/A]	[N/A]
CV_000002	[XS]	[Project Manager]	[...Global Business Iberia]	[Ingeniero Superior Telecomunicaciones ...]	[1992]	[PMP - Project Management]	[N/A]	[N/A]
CV_000003	NA	NA	NA	NA	NA	NA	NA	NA
CV_000003	NA	NA	NA	NA	NA	NA	NA	NA
CV_000004	[ORS]	[Blockchain Engineer & Venture Developer]	[... Venture Studio]	[Master's degree in Cybersecurity - UPC]	[2022]	[Business Intelligence... - M]	[Flipside Crypto]	[As per the CV, he worked as Web3.0...]
CV_000004	[ORS]	[Blockchain Engineer & Venture Developer]	[... Venture Studio]	[Master's degree in Cybersecurity - UPC]	[2022]	[Business Intelligence ... Cert. from M.]	[Yes]	[He currently works as a Blockchain Engineer and Venture Developer...]

Fig. 3. Different answer for the same prompt. Some answers were anonymized.

Therefore, a post-processing stage was established to mitigate missing information in data entries extracted by the GPT models in Fig.1. Although capturing all information within brackets allowed us to tabulate data efficiently, some entries contained incomplete information. This was resolved by repeating the GPT inference for only those entries with missing data. Consequently, all 200 data entries or CVs were accurately tabulated and ready for analysis to draw initial conclusions, as elaborated in the next section.

2.3 Analysing results

The present study utilised GPT models to analyse output data for identifying entrepreneurial activities among alumni, with statistical software R employed for this purpose. The data summary is presented in Table 1, revealing that out of the total number of CVs analysed, 174 had an engineering education degree at UPC, while 26 did not. Here, we refer to engineering education as the process of obtaining any engineering degree.

Table 1. Summary of the gathered data.

Engineering Education (EE)	Business or Management Education (BME)	Entrepreneurial Experience (ENT)	Total Data Entries
Yes	Yes	Yes	35
		No	37
	No	Yes	29
		No	73
No			26
Total			**200**

When considering the subset of CVs from individuals who had graduated from any engineering education degree, slightly more than 40% (72) of the CVs reviewed indicated that they had received supplementary education or training in business or management. Notably, although the sample size is small, individuals who had education in Business or Management exhibited a nearly 50% likelihood of possessing entrepreneurial experience, with 35 CVs as compared to 37 CVs. Conversely, individuals without business or management education were less likely to have entrepreneurial experience, with 29 CVs as compared to 73 CVs. Additionally, Fig. 4 revealed how the final academic year of their studies affected their decisions, with studying business or management higher education and being involved in entrepreneurial activities appearing more probable the more recently they completed their studies. Section 3 outlines the implications of these findings.

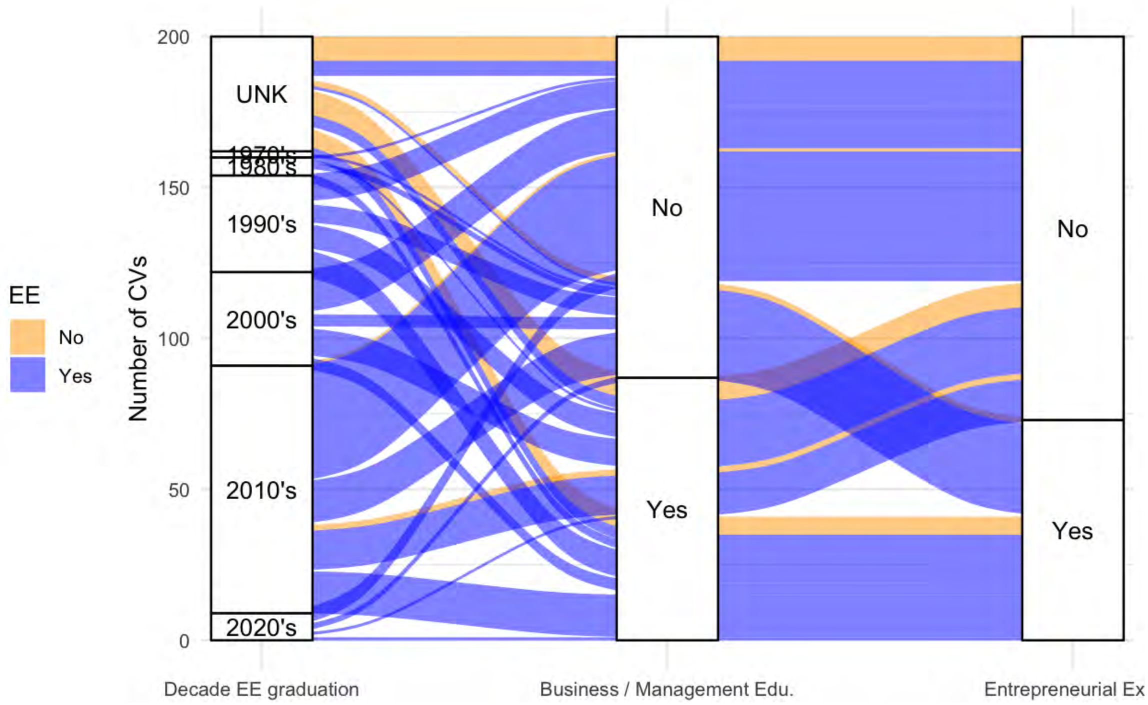

Fig. 4. Descriptive analytics for the data gathered.

3 Results

3.1 Exploratory analyses

The analysis of the collected data provides valuable insights into the relationship between education and entrepreneurial activity among engineering education alumni. The study examined 200 CVs, and information was extracted to construct a database. A logit model was subsequently developed using the constructed database, with *ENT* serving as the dependent variable, reflecting the existence of entrepreneurial activity. The independent variables were *UPC* and *BME*, representing whether a person studied engineering education or business or management education, respectively, and *Last_Year*, indicating the year of completion of studies. As demonstrated in the regression analysis, *BME* exhibited a statistically significant positive correlation with entrepreneurial activity, with a coefficient of 0.756 at the 5% level of significance. Conversely, *UPC* and *Last_Year* did not demonstrate any significant relationship with entrepreneurial activity. Therefore, the findings suggest that holding a business or management education may increase the likelihood of alumni participation in entrepreneurial activity. Nonetheless, these outcomes necessitate further verification with a larger data sample.

	Dependent variable:
	ENT
UPC	14.961
	(1,007.797)
BME	0.756**
	(0.342)
Last_Year	-0.023
	(0.016)
Constant	30.544
	(1,008.342)
Observations	163
Log Likelihood	-101.636
Akaike Inf. Crit.	211.273
Note:	*p<0.1; **p<0.05; ***p<0.01

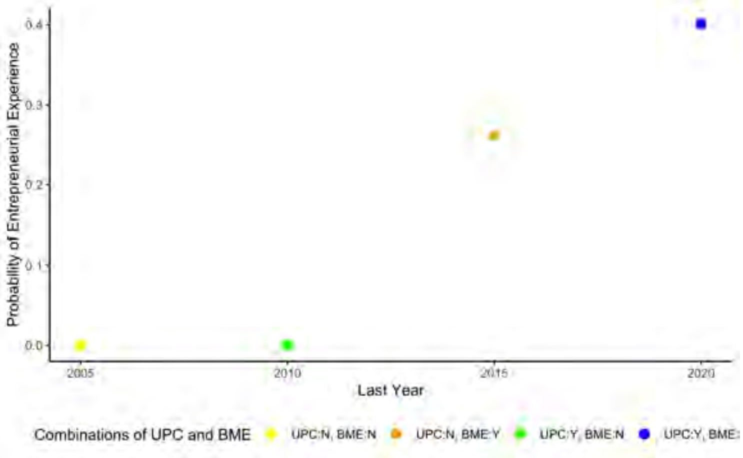

Fig. 5. Regression analysis.

3.2 Conclusions and future directions

The present study has aimed to introduce a new approach for evaluating entrepreneurship and innovation programs offered by higher education institutions in Engineering degrees. As aforementioned, previous studies have largely relied on assessing intention or skills rather than actual entrepreneurship activity, through surveys or interviews. The proposed approach utilised the new GPT technology in conjunction with the availability of resumes or CVs of alumni from a given institution. The preliminary results showed that holding a business or management education is positively associated with entrepreneurial activity among engineering education alumni, while no significant relationship was found between studying engineering education or the year of completion and entrepreneurial activity. These findings highlight the potential value of business or management education in fostering entrepreneurship among engineering graduates. Going further in our future research, we aim to add additional data sources to provide more information about the alumni in the study, particularly data related to specific courses taken in entrepreneurship and innovation while studying their engineering education degree. The expectation is that these courses have positive effect in Entrepreneurial intention and with this methodology can proxy the longitudinal data needed to assess the venture creation by the alumni (Cannata, Colombelli, and Serraino 2022), and go beyond intentions.

Nonetheless, it is important to note that the current study has certain limitations which may be addressed by future research. Firstly, the proposed method could be augmented by incorporating additional internal data sources, such as data on elective courses related to innovation, product development projects, or challenge-based learning. By doing so, institutions would be able to conduct a more comprehensive evaluation of the impact of their programs on alumni career trajectories. Secondly, while the results obtained from OpenAI APIs were encouraging, fine-tuning GPT models with additional training data could enhance the accuracy and consistency of responses across data samples. Lastly, the sample size used in the study may not be sufficiently robust to draw definitive conclusions. It is recommended that future studies utilise larger and more diverse data samples, including a balanced number of CVs from people who finished their engineering education studies in different decades, and incorporate the aforementioned improvements in order to yield more robust and sustained results.

The current study proposes a novel data-driven method for assessing the effectiveness of entrepreneurship and innovation programs offered by higher education institutions, through the combination of the proposed approach and future directions on incorporating alumni enrollment information in courses related to entrepreneurship and innovation. The proposed methodology offers a comprehensive understanding of alumni career paths and highlights the potential for AI to revolutionise the evaluation of program impact. Ultimately, this study contributes to the academic discourse on entrepreneurship education by emphasising the significance of assessing the long-term impact of entrepreneurship education on alumni career trajectories.

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EVALUATING THE FAIRNESS OF THE UNDERGRADUATE SUPPORTS SURVEY: A DIF ANALYSIS OF GENDER AND YEAR-IN-SCHOOL

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ABSTRACT

It is well established that access to social supports is essential for engineering students' persistence and yet access to supports varies across groups. Understanding the differential supports inherent in students' social networks and then working to provide additional needed supports can help the field of engineering education become more inclusive of all students. Our work contributes to this effort by examing the reliability and fairness of a social capital instrument, the *Undergraduate Supports Survey* (USS). We examined the extent to which two scales were reliable across ability levels (level of social capital), gender groups and year-in-school. We conducted two item response theory (IRT) models using a graded

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response model and performed differential item functioning (DIF) tests to detect item differences in gender and year-in-school. Our results indicate that most items have acceptable to good item discrimination and difficulty. DIF analysis shows that multiple items report DIF across gender groups in the *Expressive Support scale* in favor of women and nonbinary engineering students. DIF analysis shows that year-in-school has little to no effect on items, with only one DIF item. Therefore, engineering educators can use the USS confidently to examine expressive and instrumental social capital in undergraduates across year-in-school. Our work can be used by the engineering education research community to identify and address differences in students' access to support. We recommend that the engineering education community works to be explicit in their expressive and instrumental support. Future work will explore the measurement invariance in *Expressive Support* items across gender.

Introduction

Social relationships are essential for undergraduate students' success in engineering. The relationships that comprise social support networks come in multiple forms, such as close relationships (strong ties) with friends and family that help students with personal issues and more distant relationships (weak ties) with classmates, faculty, and advisors that help students with academic and career issues (Martin et al. 2020). Both types of relationships have been shown to improve student outcomes in undergraduate engineering, such as improving students' success in the classroom, their persistence to a degree, and their ties to professional skill development (Brush 2013; Campbell-Montalvo et al. 2022; Dika and Martin 2018). Yet access to support is *not equal* among students. Students with identities that have been historically minoritized in engineering have greater difficulties acquiring needed support and utilizing their social networks to be successful in higher education (Skvoretz et al. 2020). Additionally, students who experienced multiple years of the COVID-19 pandemic during higher education report fewer supports and social networks than peers (Douglas et al. 2022).

A present challenge for researchers and educators wishing to facilitate engineering student success is how to fairly and reliably measure the ways in which various students are supported by people in their networks—this can be operationalized as social capital. Social capital refers to the current or potential resources and supports one receives from their relationships or social network (Lin 1999; 2008). Specifically, social capital emphasizes the access to resources by the individual (called the ego), through people in their social network (called alters). In the case of higher education, students access academic and career-related resources, information and support from a variety of alters, including faculty, academic support staff, peers, and family (Martin et al. 2020; Skvoretz et al. 2020). Lin posits that there are three factors impacting the volume of social capital available to the ego: network locations, structural positions, and purposes of action (Lin 2008). The ego's access to resources is dependent on the alter's structural position, the position or authority the alter has, and the alter's network locations, such as specific characteristics of the ego-actor relationship. *Purposes of action*, the type of support the alter can provide to the ego, can be broken into two categories, expressive and instrumental supports. Essentially, instrumental actions are for obtaining new resources, while expressive actions are for maintaining resources. Expressive supports impact the "physical health, mental health and life satisfaction" of the individual and often require a mutual understanding of the need for support (Lin 2002, 4). Instrumental supports seek gains in resources, often moving the individual towards a goal.

Social capital instruments tend to measure various aspects of students' social supports, such as network characteristics (e.g., density, strength of relationships) and types of support (Gentry et al., 2023). However, these instruments have little to no evidence of validity, including little evidence of reliability (that is, little evidence that the questions in the instrument are internally consistent and fair across groups) (Chen and Starobin 2019). If the engineering education community is to become inclusive of *all* students and support them in being successful in the field, it is important to establish reliable and fair social capital measurement across groups, such as gender and year in school.

In this paper, we aim to contribute to the reliability evidence for the *Undergraduate Supports Survey* (USS), a social capital instrument that enables educators to measure the supports present in engineering students' social networks. We asked the following research questions: To what extent are the USS scales for Expressive Supports and Instrumental Supports reliable across ability levels (for undergraduate engineering students in the U.S.); to what extent are the *Expressive Supports scale* and the *Instrumental Supports scale* reliable for these students across gender groups and year in school?

Methodology

Instrument

The *Undergraduate Support Survey* (USS) (initially developed by Martin, Gipson, and Miller 2011) measures the expressive and instrumental social capital available to engineering students' through their social networks. The USS is theoretically supported by Lin's Network Theory of Social Capital and utilizes a combined name and resource generator to assess social capital available from weak and strong ties (2008). Scores for the *Expressive* and *Instrumental Supports* scales range from zero alters to provide a resource to five alters to provide a resource.
Douglas et al. (2023) performed a validation study of the USS and reported reliability coefficient alphas above 0.7 and 4 factors with factor loadings that ranged from 0.51 to 0.85. The combined validity evidence showed that USS can be used to measure undergraduate students' expressive and instrumental social capital.

Setting and Participants

We distributed the USS to undergraduate engineering students at 13 institutions in April, 2022. We selected the institutions using a probabilistic stratified sampling strategy to strive for equal representation of students from different types of institutions (Blair and Blair 2014). Across the 13 institutions, we collected a total of 2,246 responses.

We performed minor data cleaning and preprocessing to ensure data quality. The data cleaning included screening the survey for completion rate. We deleted all responses with less than a 50% completion rate— a total of 658 responses in this round of data cleaning. We also included a filter question in the survey and asked participants to choose “Not at all” as a response. We excluded responses that did not pass the filter question from the dataset for further data analysis. Using filter questions, we eliminated 354 responses. After these two rounds of data cleaning, the cleaned dataset contained 1,234 participants. Among these participants, seven did not fill out their year in program (what we are terming their “cohort”). As we were examining USS item reliability and sensitivity for students of various demographic groups, including gender and cohort, we only excluded these seven responses with missing cohort information from analysis when we were looking at the comparison between cohorts. In other words, for the DIF analysis on gender, we used the entire cleaned dataset (n = 1,234), and for the DIF analysis on cohorts, we excluded the seven responses (n = 1,227). Table 1 contains the demographic information for participants in the cleaned dataset (n = 1,234).

Table 1. Participant Demographic Information

	n	%
Gender		
Men	678	55
Women	522	42
Other	34	3
Cohort		
First year	317	26
Second year	239	19
Third year	305	25
Fourth year	273	22
Fifth year and above	93	8

Note. Other gender includes students self-identified as “nonbinary”, “other”, and “N/A” as their gender.

Item Response Theory Methods

We performed an item response theory (IRT) analysis on USS expressive and instrumental scales to examine the item reliability and sensitivity. In classical test theory, item statistics are dependent on the sample, hence the difficulty of the items is associated with the ability of the student (Reeve 2002). Whereas with item response theory, item and sample parameters are “invariant” meaning that an item’s difficulty or sample’s ability will not impact the performance of the item (Ostini and Nering 2006). This is particularly salient when examining an instrument's reliability across students’ abilities, where reliability and instrument sensitivity is important. We utilized Samejima’s (1997) graded response model to estimate parameters for ordinal, polytomous scales. The two-parameter item response theory model approximates the likelihood of a respondent selecting that response at a given trait level using:

$$P_{ik}(\theta)=\frac{e^{a_i(\theta-b_{ik})}}{1+e^{a_i(\theta-b_{ik})}} \quad (1).$$

where $P_{ik}(\theta)$ is the probability that a respondent with the latent trait (θ) selects a response option k or higher for item i (where i is the resource the alter provides). The discrimination parameter (a_i) represents the slope of the response curve, and the threshold, or difficulty, parameter (b_i) indicates the 0.5 likelihood of the respondent choosing the response immediately above or below k. In the case of this instrument, k is from zero to five, zero meaning no mentor provided that support and five meaning five mentors provided that support.

We examined 21 items for differential item functioning (DIF) across gender (e.g., women, men, and nonbinary) and year-in-school (e.g., first, second, third, fourth, and fifth year and above) using the Generalized Mantel-Haenszel statistical test with the *difR* package (Magis et al. 2010). DIF is a well-established method to evaluate if items perform differently for groups of students across the same level of ability, in this case social capital (Magis et al. 2010). Generalize Mantel-Haenszel is preferred for polytomous data and is proven to have significantly lower type I error than other DIF methods (Magis et al. 2010; Kabasakal et al. 2014). Since Mantel-Haenszel is a comparison of two groups, we conducted two gender comparisons, men and women and women and nonbinary students. We selected women as the reference group since their reported levels of expressive and instrumental social capital are higher than men and nonbinary students. For year-in-school, we grouped first and second years into a “new to university” student cohort since literature shows that first and second-year students impacted by the pandemic have had fewer opportunities to develop social capital (Douglas et al. 2022).

Results

We performed two graded response models using the standard expectation maximization algorithm with fixed quadrature. We deemed the two IRT models as having an acceptable fit based on the goodness of fit indices of the confirmatory factor analysis models specified in Douglas et al. (2023). Confirmatory factor analysis goodness of fit indices can be utilized to assess model fit for IRT models, as the model fit parameters are similar (Albert Maydeu-Olivares 2005; Alberto Maydeu-Olivares et al., 2011).

Item Discrimination and Difficulty

We found discrimination and difficulty parameters for all items in each scale. Discrimination values are judged based on Baker’s (2001) rating system, where items can have little to very high discrimination. Items in this study have moderate (a_i = 0.65-1.34), high (a_i = 1.35-1.69) or very high (a_i> 1.7) discrimination. Difficulty values (b_1-b_5) should range from [-4,4] and be evenly distributed around 0, indicating an appropriate level of difficulty across all student’s levels of social capital. Tables 2 and 3 show the mean, standard deviation, discrimination, and difficulty parameters for items in the *Expressive Supports and Instrumental Supports* scales.

The *Expressive Supports and Instrumental Supports* scales have high discrimination parameters (a_i), indicating the instrument can be used to differentiate between students based on levels of social capital. In the *Expressive Supports* scale, all items were very discriminating, with 13 items having high to very high discrimination parameters. Two items are candidates for revision due to having moderate levels of discrimination (12.6 and 12.8). The *Instrumental Supports* scale discrimination parameters are highly discriminating, with four items having very high discrimination and two items (12.4 and 13.1) having high discrimination.

Table 2. Expressive Social Capital Scale

	M	*SD*	a_i	b_1	b_2	b_3	b_4	b_5
12.1: challenges me to be my personal best	2.15	1.51	1.69	-1.50	-0.35	0.46	1.12	1.94
12.2: checks on my progress	1.90	1.44	2.02	-1.26	-0.14	0.64	1.32	2.01
12.3: discusses school, academic and career topics	2.34	1.55	1.77	-1.73	-0.46	0.28	0.92	1.61
12.5: encourages me about my studies	2.05	1.52	2.08	-1.20	-0.25	0.45	1.09	1.85
12.6: is a mentor	1.20	1.32	1.12	-0.47	0.73	1.72	2.67	3.85
12.8: supports me with other resources	1.50	1.47	1.36	-0.82	0.28	1.11	1.85	2.64
14.1: [discussed] Your mental or emotional health	1.46	1.40	2.44	-0.62	0.22	0.93	1.57	2.13
14.2: [discussed] Your physical health?	1.18	1.28	2.04	-0.38	0.51	1.29	1.94	2.73
14.3: [discussed] Disappoints you've had	1.38	1.40	2.68	-0.50	0.29	0.94	1.58	2.10
14.4: [discussed] Difficulties you've faced	1.97	1.61	3.05	-0.91	-0.13	0.46	1.00	1.49
15.1: Made an effort to stay in touch (contact you if it has been a while)	1.58	1.45	2.65	-0.63	0.08	0.80	1.41	2.01
15.2: Ask you how classes were going	2.19	1.57	3.13	-1.14	-0.30	0.32	0.86	1.42
15.3: Encouraged you to keep going when you struggled	1.88	1.57	3.12	-0.84	-0.05	0.53	1.07	1.57
15.4: Asked about your levels of stress	1.28	1.33	2.61	-0.46	0.38	1.07	1.70	2.24
15.5: Initiated conversation with you	2.08	1.65	2.87	-0.93	-0.22	0.37	0.91	1.44

Difficulty parameters (b_i) for the *Expressive and Instrumental Supports* items indicate that approximately half of the items have moderate to high levels of difficulty and may not accurately measure students with low levels of social capital. Items in both scales demonstrate a floor effect, negatively skewed difficulty parameters, meaning the center difficulty parameter (b_3) is shifted higher than zero; this indicates that students must have already high levels of social capital to be able to select that an alter provided a resource. Items lacking an evenly distributed *b* parameter range may poorly capture ranges in students' social capital, since items are only able to capture students with high social capital ability. *Expressive Support* items 12.6, 14.1, 14.3, and 15.4 all have negatively skewed b parameters. All but one Instrumental Supports scale item (13.2) has shifted *b* parameters.

Table 3. Instrumental Social Capital Scale

	M	*SD*	a_i	b_1	b_2	b_3	b_4	b_5
12.4: helps me with course selection	1.11	1.08	1.51	-0.67	0.83	1.96	2.72	3.79
12.7: suggests networking opportunities	1.06	1.22	2.28	-0.23	0.71	1.44	2.09	2.65
13.1: tries to involve me in extracurricular activities	1.16	1.27	1.36	-0.37	0.70	1.58	2.59	3.55
13.2: gives me advice on academic and/or career options	1.98	1.47	2.02	-1.32	-0.16	0.59	1.29	1.87
13.3: suggests job or graduate school opportunities	1.19	1.25	2.31	-0.38	0.50	1.27	2.02	2.60
13.4: introduces me to people in their professional network	0.70	1.03	1.87	0.27	1.19	1.95	2.79	3.60

DIF analysis

We conducted three DIF analyses for the *Expressive* and *Instrumental Supports* scales. DIF items that with both statistically significant and having substantial effect size should be reviewed to improve item functioning. Substantial DIF is considered as effect sizes in the moderate ($1 \leq |\Delta MH| \leq 1.5$) to large ($|\Delta MH| \geq 1.5$) ETS delta scale range (Holland and Thayer 1986). Effect sizes below ($|\Delta MH| \leq 1$) are considered negligible and not needed to be further analyzed.

The *Expressive Supports* scale reported the largest number of items with DIF. Six items have significant DIF between men and women, however only four had substantial effect sizes, items 12.2, 14.1, 14.4 and 15.5. Three of the four items favored women over men, whereas item 12.2 favored men. Items 12.3, 14.4, and 15.5 had substantial DIF between women and nonbinary engineering students, favoring nonbinary engineering students. DIF analysis of nonbinary students should be examined carefully, as the small sample of nonbinary students may impact the power of the DIF analysis (Lai et al., 2005); despite the small effect size, these items should be reviewed for DIF. We found no DIF between student year-in-school cohorts.

We found the *Instrumental Supports Scale* to be adequately fair across gender and year in school, with only two items reporting DIF. Across gender, item 13.2 had significant but unsubstantial DIF favoring men over women. No DIF was found between nonbinary students and women. Across year-in-school, only one item, 13.4, had substantial DIF in favor of third, fourth, and fifth-year and above students.

Conclusions, Limitations, and Implications

We utilized IRT and DIF analysis to answer the two research questions, finding the *Expressive* and *Instrumental Support scales* to be reliable across levels of social capital and fair in assessing social capital across gender and year in school cohort. Our results indicate that the items are able to sensitively capture variance in students' social capital but may be overly difficult, resulting in less reliable assessment for students with low levels of social capital. DIF analysis showed that the *Expressive Supports* scale has multiple items that favor women and nonbinary engineering students, whereas the *Instrumental Supports scale* has little to no DIF.

To address the high-difficulty parameters of the *Instrumental Supports* scale, we propose revising items to make what is considered accessing a resource more explicit. For example, a faculty member introducing a student to a colleague might not seem like networking to a first and second-year student, although the faculty member would recognize it as such. This difference in interpretation could be a potential explanation for the DIF in *Instrumental Supports* item 13.4.

A potential explanation of the DIF seen in the *Expressive Supports* scale could be explained by the access to specific examples of the expressive support, particularly by those who are minoritized in engineering (women and nonbinary students). The prevalence of gender-specific engineering organizations focused on well-being and retention may play a role in making expressive supports explicit to those students. Douglas et al. (2023) found that men in engineering have fewer alters providing expressive supports, potentially related to being in organizations that may not focus on well-being. Our work confirms the need for engineering education community members to provide explicit expressive support to *all* engineering students.

One limitation of this study lies in the method selected; DIF analysis is not ideal for examining fairness between more than two groups and when sample sizes are uneven. We have utilized methods that will result in the best power and error management for our sample sizes, but future work should examine fairness by utilizing multi-group confirmatory factor analysis or ordinal logistic regression. Specifically, future work should explore measurement invariance for gender groups across expressive and instrumental supports.

An important implication of our work for the international engineering education community is the opportunity to intentionally provide instrumental resources to students with whom we interact. For example, engineering instructors could make announcements about undergraduate research opportunities in their department or student organization meetings during class. These types of instrumental supports are small actions that can make a large difference in students' social capital access. Another important implication of our work lies in the utility of the USS for engineering education researchers. Our work has demonstrated that researchers can confidently use the USS survey to examine expressive and instrumental social capital in engineering undergraduates across year-in-school.

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CONVERSATIONS: TEACHING SUSTAINABILITY IN ENGINEERING

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ABSTRACT

Our research focuses on embedding sustainability in the engineering curriculum in ways that are efficient, coherent and inclusive. An important strand of work within this wider remit is finding suitable approaches for promoting collaboration between institutions and academics and advance the understanding of what ‘sustainability’ means in engineering education in the first place, by producing reliable data that can inform our future practice, leading to institutional change. In this paper, we report and discuss the organisation and the findings of a series of inter-institutional conversations that took place during two in person workshops, with the central theme of embedding sustainability in the engineering curriculum, held at a University in the UK during spring 2022 and the online meetings and interactions that followed. These meetings provided an opportunity for engineering educators from universities in the southwest of England to share experiences from their current practice when teaching about and for sustainability. The workshops explored the feasibility of setting up of an online platform for sharing teaching and learning resources and techniques, all relating to sustainability issues in an engineering education context. They also spoke to the importance of collaboration and cooperation

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1 INTRODUCTION

The 21st century has seen the advancement of sustainability seen as a core value in all aspects of our society, including higher education. The United Nations Educational, Scientific and Cultural Organization (UNESCO) declared 2005 to 2014 to be the Decade of Education for Sustainable Development, in an attempt to coordinate efforts within higher education institutions to achieve a sustainable future (Thürer et al 2017). With this advancement in mind, there have been many publications in recent years on the subject of the integration of sustainability into the engineering curriculum. Most of the research involves the presentation of cases studies (Weiss and Barth 2019; Leifler and Dahlin 2020) from a quantitative and positivistic perspective by studying “what works" (Gutierrez-Bucheli, Kidman and Reid 2022). A second prominent line of research focuses on defining the competencies students should develop during their degrees to contribute to the resolution of conflicts related to sustainability (Quelhas et al 2019). Limited work considers actual student outcomes, that is, exploring the differences between actual and expected learning outcomes. The literature lacks evidence of monitoring students’ interior transformations (Gutierrez-Bucheli, Kidman and Reid 2022). Also, there are not many research studies on the barriers, at institutional and individual academic level, to embedding sustainability in the curriculum.

Four main impediments (Gale et al 2015) have been identified: (1) disciplinary contestation (confusion over what sustainability means); (2) institutional fragmentation, preventing real interdisciplinary approaches due to difficulties in true collaboration; (3) economic globalisation, that has transformed higher education into just another unsustainable market; (4) time-pressed academics with no time to engage fully with the challenge.

It seems, from the research landscape, that there are many pockets of good practice; that there is a proliferation of courses and degrees in sustainability studies but, embedding sustainability as a core across the higher education curriculum has not happened. Most engineering programmes focus on standard engineering science, which can be traced back to the technological race during the cold war (Leydens and Lucena 2017). Whilst some social and ethical aspects are present in most programmes, there is a persistent divide between the social and the technical. In fact, past studies such as (Cech 2014), point out that student interest in public welfare declines over the course of their engineering degree.

Many engineering programmes are attempting to embed sustainability into their curriculum in isolation and substantial benefits could be achieved if joining forces in creating materials, with an emphasis on ontology, detailed methodology and practice. The idea of a platform for collaborating and sharing resources was inspired by the work presented in (Davidson et al 2016), where the need of such as repository was discussed. In this work, the outputs of a workshop discussing the need of the repository were presented with a focus on the practical side - on assessing the community’s preference for a repository and identifying barriers to its adoption.

In our work, we widen the concept of the repository presented in Davidson et al and we discussed the idea with a selected group of colleagues sharing our journeys of embedding sustainability in engineering education. We also argue that, rather than creating a passive repository, we should create an online collaboration space, where we don’t only share resources, but also experiences and we enable academic to connect and expand their networks. During May and June 2022, two in-person workshops on Teaching Sustainability in Engineering brought together 28 educators to discuss current practice and the feasibility of setting up a shared resources platform with teaching and assessment materials related to sustainability in engineering education. The participants were all academics teaching sustainability in an engineering context at the universities of Bristol (host), Bath, Cardiff and Exeter. We start this paper by explaining our approach to organising the workshops, including their format and predefined themes. This is followed by the presentation and analysis of the discussions around the predefined themes. We then reflect on the emerging areas outside the predefined themes and future steps.

2 METHODOLOGY

In this work, a workshop is used as a research methodology, with the aim of gathering reliable information and feedback about teaching sustainability in engineering that will lead to organisational change. Workshops are ideal for studies that are emergent or unpredictable (Ørngreen and Levinsen 2017), with the findings feeding back into future practice. The central idea of the approach is for participants and researchers to work together in a collaborative manner, with the researchers retaining the control. We considered the different roles that researchers can have in a workshop as research methodology, and two members of the research team adopted clinician roles, focusing on participant needs while the third adopted an ethnographer role, focusing on the research (Ørngreen and Levinsen 2017). An emphasis was placed on not treating participants as consultative research objects, but as research partners. This methodolofy gained ethics approval from the host institution.

From a methodological point of view, both primary and secondary data were collected from the workshops. Primary data is produced in real time, in our case, researchers produced personal notes and both participants and researchers collected their thoughts using jamboards, a web-based whiteboard system. Secondary data resulted from the retrospective analysis and representations of '*what happened'* during the workshop.

The workshops were designed using a conceptual format (Ørngreen and Levinsen 2017), with a set of predefined phases: we started the discussion by presenting a predefined set of themes for discussion, focusing on current practices and the teaching resources that are used to embed and teach sustainability in the engineering curriculum. We tried to define the need and barriers for a repository and had conversations about the challenges of teaching sustainability in engineering in general and the setup and maintenance of a repository. Some other avenues for discussion emerged during the workshop and will be detailed in the following sections. The predefined themes can be summarised as a reflection on:

- *What students should know: intended learning outcomes.*
- *Our current practice and teaching resources.*
- *Feasibility of creating an online platform for collaboration.*

The outcomes of the two workshops are merged and presented in the following sections.

3 WORKSHOP THEMES: ANALYSIS OF THE DISCUSSIONS

In this section we report on the discussion around the three predefined themes questions already mentioned in Section 2.

Theme 1: What students should know: learning outcomes.

Central to the idea of intended learning outcomes (ILOs) is that teaching should be planned based on the competencies students should develop instead of the results of the learning process. In general, HE institutions in the UK now follow the principle of constructive alignment (Biggs 1996), which means teaching activities and assessment should be aligned to the ILOs. This model has been endorsed in HE policy worldwide. In Europe, educational programmes are said to be more transparent and comparable due to this framework (Havnes and Prøitz 2016). There are some important concerns about this model, as it can be managerial, diminish academic freedom and be focused too much on what can be measured. This last concern is very important when talking about sustainability teaching because many of the competencies we are set to assist the students in developing can be abstract and difficult to quantify and/or express as learning outcomes (Erikson and Erikson 2018). If our students should develop a disposition for critical thinking that includes self-reflection or critical reflection on the world at large, this cannot be separated from the students' private worldviews. Writing learning outcomes about such outcomes implies expectations of performativity that can be seen as an infringement on students' academic freedom (Macfalane 2017). Creating learning outcomes that specify a 'correct' outcome of critical thinking is contrary to the very idea of critical thinking (Erikson and Erikson 2018).
Participants attempted to define intended learning outcomes in relation to teaching sustainability in engineering. The gathered information is shown in Figure 1 as a word cloud, where the largest fonts show the highest frequency of a notion. Notions such as awareness and understanding appear quite a few times. We need to emphasise that we are not talking about awareness and understanding in a strict disciplinary context but in a generic context: students need to be able to develop awareness and understanding outside their areas of expertise.

Figure 1. Intended Learning Outcomes defined during the first workshop

Participants agreed that in order to embed and integrate sustainability into the curriculum, we need to broaden the base of the engineering education and make it more interdisciplinary. A limitation to new approaches is the workload which is already high for both students and staff. Teaching new topics would require us to abandon some of the existing content. The professional institutions that accredit engineering programmes may not accept the dilution of the technical content. However, the new edition of the Engineering Council framework for accreditation in the UK does move towards explicitly including aspects of communications,

sustainability, management, or EDI, compared to its previous versions (Engineering Council 2020).
The conversation evolved from critical thinking, to system's thinking and even more philosophically, the purpose of education. For most stakeholders, from policy makers to councils, the current focus is on employability: it seems that employability is the key concept in higher education. Graduate employment rate is often used to assess the quality of university provision, despite employability and employment being two different concepts (Cheng et al 2021). It was also discussed how interdisciplinary systems and critical thinking might not be a key factor for employability.

Theme 2: Our current practice and teaching resources.

In the second part of the workshops, we focused on practical uit aspects: what are we currently doing when teaching sustainability. We posed these three questions to the participants:

- *What materials do you currently use in your teaching?*
- *Are there any teaching techniques that have worked particularly well or particularly poorly for this topic?*
- *What would make it easier for you to teach sustainability in engineering?*

Participants were divided into teams for discussion. When asked about the teaching materials they use, participants mentioned traditional tools such as textbooks for technical content or journal articles which we would expect to be consulted. They also mentioned a wealth of other resources which are much more in tune with the latest developments, such as newspaper articles from the Guardian or the Financial Times, IPCC reports, Ted Talks, Fly zero reports by the Aerospace Technology Institute, governmental reports, interviews with professionals, games, news or podcasts. These resources are inherently dynamic and take up significant time to research and keep up to date, compared with the traditional science-focused books that have been known to us and have been part of the curriculum for a number of years.
In answer to the second question, participants brought up techniques such as: role play, guided discussions on current events, letting students think outside the box, setting grand challenges, linking activities with people's lived experiences, creating strong links with technical content, using anonymous polling software or working with external partners and entities such as Engineers without Borders. These activities require careful preparation and are more challenging to manage, adding again to staff workload and stress, which was identified as a challenge in the second part of the question. One of the most important issues identified was keeping the students engaged with sustainability and other complex wicked problems. Engineering students typically learn to solve well-structured problems using established methods to arrive to a solution (Lönngren 2019). Other challenges centred around the difficulty of catering for very large cohorts, staying abstract or teaching sustainability in isolation, in parallel with the technical content.
The last question in this section was about what would be helpful for the participants in their sustainability teaching. All answers hover around two areas: (1) fully understanding what is going on at university and programme level with clear

definitions of what we are trying to achieve (2) collaboration and sharing, a good indication of the need of the proposed online platform.

Theme 3: Feasibility of creating an online platform for collaboration

In the final part of the workshops, we focused on the idea of developing an online platform with teaching materials on sustainability. Again, groups were formed to discuss the answers to the following questions:

- *Would you be interested in using an online platform for teaching materials, sharing your own teaching materials, or both?*
- *What would encourage you to use and share materials on the platform?*
- *What would you expect from the online materials?*
- *In your opinion, what are the main challenges for such a platform?*

In answer to the first question, there was a consensus that a platform would be a helpful tool. For the second question, four main areas emerged: (1) ease of searching materials and a clear user guide, (2) hosting interactive/inclusive/rich materials, (3) having information about the source of materials and the authors and (4) attributing sources to authors.
We also talked about additional information that could be added to the teaching resources such as the setting in which they should be or have been used (cohort size, staff to student ratio, student's feedback on the activity) and also adding AHEP tags, relating material to accreditation criteria. The need for clear licencing rules was also noted, and the need of a mechanism for attribution to authors that could be used for career development and an indicator for career progression was reiterated. Moving into the last of the pre-defined question, the challenges for establishing a platform, three main issues were discussed: copyright, the cost of the curation of the materials and worries about sharing your own materials with others: '*Is the content right? Will others agree/like it?'.*
The issue of curation is very important, in the past there have been several attempts to create networks and repositories that died after a short while due to lack of funds for maintenance. Several ideas to produce income were discussed such as authoring a fee-paying online book, creating an open access journal or hosting the repository under the university IT umbrella.

4 EMERGING THEMES

As anticipated, a series of relevant associated issues emerged, such as the lack of a clearly defined ontology for sustainability in engineering education and the tensions arising at different levels due to conflicting views on what sustainability means and its purpose in engineering in general, and in engineering education in particular. These are all part of the wider research project we are undertaking.
First and most important, the need to take a step back from learning outcomes and explore the definition of an ontology for sustainability teaching in engineering. The main challenge we identified was that sustainability means different things to different people, so we need to accommodate that clearly into the ontology, we need to embrace and work with different views on sustainability. There is a fundamental debate whether to adopt a strong or a weak conception of sustainability (Ayres, Van den Bergh and Gowdy 2001) engineering students need to be aware of all

approaches and be able to take their own position in the sustainability discourse (Advance HE 2021).
Secondly, there was a clear appetite and need for collaboration, not only with academics already actively working on embedding sustainability in the curriculum, that tend to have a similar view on what sustainability means, but also to reach out to others not engaging or not interested in the sustainability agenda. We also discussed the need to more actively embed the student voice in the definition of our frameworks by offering opportunities for students to work as researchers on our projects.
Building on the reflections and findings presented in this paper, our wider work includes establishing a definition of an ontology that acknowledges the different facetes of sustainability, the mapping of current provision against this ontology, the creation of test cases with examples. This is work in progress and it has been developed in close collaboration with undergraduate and postgraduate students, working as co-researchers.

5 SUMMARY AND FUTURE WORK

In this paper we present the outcomes of two cross-institutional workshops organised in the context of setting up a platform for sharing resources for teaching sustainability in engineering education. The workshops covered three thematic areas around learning outcomes, current practice and associated approaches and barriers, and the development of teaching resources.
Based on the positive feedback and discussions held in the workshop, we have created an online platform featuring the desired characteristics and functionality. This is already active and it now needs to be populated with materials and resources. Once the first set of resources are added, we will invite academics to register and start sharing practice and collaborating.
Future work includes the creation of training resources to inform and inspire academics who do not currently engage with the sustainability agenda.

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JOB COMPETENCIES: EXPERIENTIAL LEARNING FOR ENGINEERING STUDENTS

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ABSTRACT

This study investigates the learning of engineering students within the context of career-focused education. Often the technical and mathematical sciences on which engineering courses are built fail to explain the entirety of the landscape of practice. The main objective of this study is to capture various constructs produced by an undergraduate student while relating to his social interactions and experiences in an authentic workplace. The study also explores the student's responses to real-world contexts. This paper details a single case chosen using purposeful sampling, which investigates the phenomena of a student intern transitioning from engineering education to practice. The presented case is information-rich, and the intern's story provides a detailed insight into the complexity of a student's first encounter with engineering practice. This study highlights the conflict between engineering practice and engineering education and the corresponding emotional transition for graduate engineers. In particular, this study gives an intern's perspective of transitioning from education into practice and his emotional journey of self-learning, adapting to new situations, endeavouring to focus on clients' requirements, and ultimately finding his

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place on the engineering team. The intern’s story supports the advocacy to reshape university engineering education so students’ values, practices and expectations align better with practice.

Conference Key Areas: Engagement with Industry and Innovation, Curriculum Development

Keywords: engineering practice, career-focused education, real-world contexts, internships, self-learning

1. INTRODUCTION

The main aim of this study is to generate new knowledge on the phenomena of a student intern transitioning from engineering education to practice. It is asserted that transitioning from engineering education to practice is highly complex, critically important, and troublesome. (Hawse and Wood 2019, Trevelyan 2019, Baytiyeh and Naja 2012, Anderson et al. 2010) Due to misunderstandings about engineering practice, curriculum reforms addressing graduate attributes and workplace skills have not significantly improved graduate employability. (Trevelyan 2019) Furthermore, while limited, the literature exploring the design of workplace induction programs to assist graduate engineers in transitioning to professional practice is from an education perspective rather than the workplace. (Hawse and Wood 2019) As such, engineering students have incomplete views of engineering practice, and the type of work students expect to do in their future careers is vague. (Karataş, Bodner, and Ünal 2016, Goold, 2015) Most early-career engineers learn to practice by trial and error, and a fortunate few have helpful mentors to guide them. (Trevelyan 2019) This same author advocates reshaping university engineering education, so students’ values, practices and expectations align better with practice. (Trevelyan 2019). It is anticipated that the findings of this study, investigating the transition to practice for engineering graduates, their readiness to perform job tasks successfully in real-world work environments and an account of graduates' early experiences of engineering practice will contribute to the knowledge on the design of undergraduate engineering programmes. The research question explored in this study is: what challenges does a student intern encounter when transitioning from engineering education to practice?

2. METHODOLOGY

This study captures the story of a student’s first encounter with engineering practice. The undergraduate electronic engineering programme at TU DUBLIN, Tallaght, does not include formal work experience, and graduates’ first encounter with engineering practice is usually after graduation. This study uses purposeful sampling: it proposes to capture the knowledge and meaning one undergraduate student who recently completed an internship in engineering practice constructs from his social interactions and experiences in an authentic workplace and his responses to real-world contexts.

Contrary to quantitative logic, where large sample sizes are required, a single case is chosen because the case is of interest (Stake 2005). Case study research scientifically investigates a real-life phenomenon in-depth. Typically, a case study has a sample size of one. A single case may be chosen to explore deeply new phenomena (Miles and Huberman 1994) to gain rich and detailed insights into the complexity of social phenomena. (Collis and Hussey 2009) Purposeful sampling allows the researcher to focus on a phenomenon and to explore information-rich cases where the researcher can learn a great deal about issues of central importance to the education of future engineers (Schoch 2016). This study provides a detailed analysis of the transition to practice with the student as the context. While a larger sample size would generate a wider perspective of the phenomenon, only one intern with experience transitioning from engineering education to engineering practice was available to participate in this study. This is an information–rich case providing multiple insights into the context of this phenomenon.

An open-ended, informal interview was employed to explore and probe the student's experience of transitioning from university to practice and allow the interviewee to respond in his language. Open-ended questions were selected to reduce bias. The interview data were analysed qualitatively using an open coding system involving the grouping of survey response sections that share some common meaning. The findings result from the subsequent emergence of distinctive themes from the coded data.

3. RESULTS

The intern (alias Tom) is a final-year engineering student in Ireland who previously trained as a nurse in the Philippines. At the time of the interview, Tom had just completed an internship. The internship was his only experience in engineering practice. Tom was completing his final year of electronic engineering studies and looked forward to taking up a graduate engineering position with a multinational company.

A childhood interest in computers contributed to an interest in engineering, and Tom contrasts the "*risky*" nature of the medical field with his "*very big expectations*" of engineering. In addition to working with technology, computers and innovation, Tom's perception of an engineer is "*making life easier in terms of medical and other fields of work*." During his internship, Tom worked with an electronics company that provides solutions for the aerospace and consumer electronics industries. His work was in the applications department. Four themes were apparent from an analysis of the intern's internship account.

3.1 Theme 1: The contrast between engineering education and practice is evident.

Unlike college, working in engineering practice requires "*some client perspective*" and a real-world understanding of ethical issues, typically in the form of regulations, trade issues and special trade agreements with specific countries, some uses of artificially intelligent products and employee health and safety. The multidisciplinary aspect was a new experience for Tom.

It took a few weeks for Tom to understand his role in engineering practice. The "*quicker way of working, taking short cuts*" during the internship contrasts with the "*more structured approach learned in college*." While Tom likes objective solutions, "*I try to have a single value I can give to my manager*"; however, "*when I show the team how I did it, they were unsure*." Similarly, Tom's role did not have a "*structured objective it is more flexible … since some projects might not work out or we might need to go to another problem that the client is facing*". Time management also posed a challenge for Tom, as the focus at work was to "*deliver more rather than learn more …. and deadlines.*" There was no time allocated to the "*more in-depth learning*" that Tom required to get the work done.

Similarly, learning in the real-world contrasts somewhat with college learning; Tom says, "*I had to adapt to a quicker way of working, taking shortcuts… I can skip steps I learned in college*". Tom describes a technical project he completed as "*more about how you approach it and how you plan it rather than the technical content.*" He learned that communications are more important than the technical. For example, Tom found it difficult to omit the highly specialised part of a technical user guide he developed, which "*will be available on our website and accessible to our clients, engineering students and non-engineer,*" and he had to "*make it simpler to read*."

3.2 Theme 2: Transition to practice is emotional.

Tom was very "*anxious*" and "*excited*" about the internship. He was anxious because it was "*a real-world scenario rather than a theoretical scenario of the classroom*." The excitement stemmed from the experience to be gained. However, Tom experienced many difficulties finding his "*place in the team.*" "*It's hard to level myself since I'm working with the team who have been there for years,*" and "*the team was really busy doing their own jobs, but I tried to arrange a meeting with them.*" "*I tried to catch up with them… I tried my best to learn everything and to apply that to the project I was working on*".

Tom was "*more confident*" using college-learned strategies compared to the company's ways. Rather than immediately adopting the company's strategies, Tom says, "*I combine both strategies and come up with my way that seems to work as well …I am more confident that way*". When his manager "*commended*" him for doing a "*good job*" and his work was featured in the company's science fair, Tom says, "*that felt really good.*"

Tom developed a real-world understanding of ethical issues. As the company developed applications for customers, the company could regularly encounter customers in non-compliance with regulations, trade issues and special trade agreements with specific countries, usage of artificially intelligent products and employee health and safety. Tom struggled with the political reputation of some of the company's clients. Similarly, Tom works with a *"fear of making mistakes.*" For example, he is sometimes "*curious*" to learn by "*testing products at their limits while turning off warnings,*" but there is a part of him that is "*afraid."* Consequently, he tries to be "*careful.*"

When asked about becoming an engineer, Tom says, "*it fulfils what I wanted to do. I feel really great. I feel privileged to have another opportunity to learn what I really want to do and what I can contribute to the industry".* He adds that having the job offer before graduating "*is a very uplifting feeling. I have never felt this before*" and "*after nursing graduation in the Philippines, I needed to sit an exam to be registered and wait to apply for a job*."

3.3 Theme 3: Self-learning, planning, adaptability and client- perspective are key work strategies.

On the first day, Tom "*did not know what they wanted me to do and what they wanted me to learn?... I tried to structure what I needed to do and questions to ask my mentor/manager, what should I do next*? … *What are the goals they want me to do?"* Tom says, "*I tried my best to learn everything and to apply that to the project I was working on …. there was always room for me to make myself busy*". Tom relied on "*self-learning and perseverance*"; he says, "*I'll try and try until I get it*." Tom stresses the importance of "*self-learning*"; he acquired this ability when training for and practising nursing in the Philippines whereby "*there is no learning guide, they give us a list of topics, and it is up to us how we learn the stuff*." Planning is another skill that Tom employed during his internship. Tom learned this skill in nursing and in an undergraduate engineering module called Management Practice. Tom describes a technical project he completed as "*more about how you approach it and how you plan it*."

Tom lauds his "*adaptability*" skills; "*adaptability is where I engage as much as possible to learn things and become familiar with a company's tools so I can contribute*." *Having "some client perspective"* helps Tom understand his role; "*once I know what the client wants, it makes it easier."*

3.4 Theme 4: Engineering practice is a diverse community of team members, other engineers and clients.

While the team was helpful, Tom experienced many difficulties finding his place in the team. His familiarity with C++ software allows him to interact well with the software engineers who set the tool parameters to be used by the applications engineers. Having "*some client perspective*" helped Tom understand his role. Regarding employee diversity, while the company's employees are mostly Irish and American, "*only one I noticed different from my group, he prays a lot, and I respect that.*"

Tom believed that placements/internships prepare students well for the real world of engineering. While his new job is in a different technology sector, Tom claims to "*have the advantage of confidence gained during the internship; I can try to adapt what I have learned there with [the new company*." While this new company is engaged in a very different technology, Tom is looking forward to the new job and regards his "*ability to learn,*" "*planning,*" "*adaptability to environment and systems,*" and "*time management*" as the key skills he is bringing with him to the new company.

Regarding the hiring process for his new job, Tom says, "*they do not seem to care about engineering skills. They are only interested in problem-solving skills, people skills and soft skills.*" They "*focus on how you deal, solve, approach, plan, assess, validate, deal with the team, how you are going to function in their team and how you deal with them rather than how you deal with their product.*"

4. ACKNOWLEDGEMENTS, SUMMARY AND DISCUSSION

4.1 Acknowledgements

The authors would like to acknowledge the intern's participation in this study and for sharing insights of his first encounter with engineering practice with the engineering education community.

4.2 Summary

This study found that the engineering student encountered four main challenges when transitioning from engineering education to practice: (i) adjusting from theoretical to practical strategies, (ii) emotional and social aspect is a new experience, (iii) how to respond to new methods and challenges and (iv) participating in a diverse community. This study highlights the contrast between engineering education and practice. Technical content, structured learning and objective solutions are integral to engineering education, while engineering practice involves clients, deadlines, shortcuts, multidisciplinary approaches and communications. There are also emotional differences. Confidence with college-learned strategies is set aside in favour of anxiousness and uncertainty about goals and methods. Additionally, there are social challenges; learning to communicate with and work with busy, experienced colleagues is particularly challenging. Furthermore, there are new ethical concerns. The intern outlines how self-learning, planning, adaptability and client perspective are key work strategies that assisted his transition from education to practice.

4.2 Validity of study

While this study has a sample size of one, the findings are valid; the intern is an information-rich case, and his story emerged from an open-ended interview which was analysed qualitatively using an open coding system. While a single case may be used to gain rich and detailed insights into the complexity of social phenomena. (Collis and Hussey 2009), a further study with a greater sample could be used to get a wider perspective of the research topic.

4.3 Research Question

The research question sets out to determine the challenges a student faces when transitioning from engineering education to practice. The outcome is the four themes. A significant challenge engineering practice presents is practising engineers' reliance on tacit knowledge, given that engineering education is based on explicit knowledge. The intern's story confirms that graduate engineers' over-attachment to objective solutions restricts both their vision of engineering solutions and the bigger picture of engineering practice, particularly where client factors and a background of incomplete information constrain real world practicality. In addition, a preference for a theoretical approach over subjective analysis contributes to communication difficulties. Furthermore, this creates an affective hurdle for graduate engineers to overcome when they begin working as engineers as evidenced by the intern who experienced many difficulties finding his "*place in the team.*" (Goold and Devitt 2012)

4.4 Implications for Engineering Education

The intern's story demonstrates that engineering education is somewhat misaligned with engineering practice. While engineering education comprises mostly technical knowledge, the business and organisation communities, which are so important in engineering practice, are often neglected in engineering education. This neglected aspect is evidenced in the intern's story as he struggled to set aside the technical content learned in university in favour of multidisciplinary problems, flexible objectives, client perspective, tacit knowledge, shortcuts, deadlines, communications, social interactions and ethical concerns, which dominate the landscape of practice.

This study provides further evidence for the divergences between engineering education and practice. A comparison of competencies required by practising engineers and competencies developed by students highlights gaps in preparation for professional practice. In particular, students' global, professional, thinking, ethical, business, teamwork, confidence and communications skills are inadequate. (Goold 2015)

The four themes emerging from the intern’s story align with the research demonstrating that complex workplace relationships and social performances shape and are shaped by technical outcomes. (Trevelyan 2019) Learning from co-workers is the primary learning method in engineering practice and it is a means to understanding what is expected of new hires. (Korte 2009, Korte et al. 2008) However, while building relationships and mentoring relationships are key to navigating engineering practice, the most troublesome experience encountered by newly hired engineers is learning how the organisation's social system operates. (Korte 2009) Additionally, an ethnographic study of new engineers in their first job year shows that mentoring new engineers is “ad hoc and fleeting” and learning arrangements between new and more senior engineers are often rebuked due to corporate structure and hierarchy. New engineers can be isolated while struggling to find a place in their latest work, impacting their identity formation. (Davis et al. 2018) These authors conclude that systematically incorporating mentoring relationships with experienced practising engineers into the curriculum would assist the socialisation of new engineers and improve engineering graduate employability. (Davis et al. 2018)

It is asserted than an ability to do engineering work comes from the experience of working in an engineering environment, watching experienced engineers estimate, working out real problems and how they view the bigger picture. (Goold and Devitt, 2012) Internships provide graduate engineers with this tacit knowledge. One set of authors state that while preparing students for professional practice is the main objective of work placement programmes such as internships, it is critical to provide systematic learning guidance and effectively integrate interns into the organisation quickly. (Zehr and Korte 2020) They assert that students must also recognise connections between what they learn in the classroom and the workplace to apply knowledge from one environment to another effectively. (Zehr and Korte 2020) However, engineering is complex; for example, the engineering profession “consists of bundles of interrelated practices and material arrangements.” (Rooney et al. 2013) Additionally, engineering practice comprises three types of communities: engineering (produces solutions to or manages problems of markets and societies), business (addresses the commercial needs) and organisation (group of people working within predominantly social structures and processes). (Korte 2019) Furthermore, engineers’ work identity centres on their ability to be problem solvers, team players, and life-long learners in various milieus. (Anderson et al. 2010)

It is concluded that transitioning from education into practice is an important part of professional engineers’ development. The intern’s emotional journey of self-learning and adapting to new situations supports the advocacy to reshape university engineering education so students are equipped with skills such as self-learning, perseverance, planning, adaptability, client perspective and an ability to navigate the social system as they transition into engineering practice. Hence, incorporating an Engineering Practice module into engineering education would greatly enhance it.

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ONCE UPON A TIME IN THE CASTLE OF ENGINEERING EDUCATION: THE MAGIC OF STORYTELLING FOR NEURODIVERSE STUDENTS

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***Conference Key Areas**: Equality Diversity and Inclusion in Engineering Education & Innovative Teaching and Learning Methods*
***Keywords:** Neurodiversity, Storytelling, Pedagogy, Cognitive Load, UDI Framework*

ABSTRACT

Neurodivergent engineering students face unique barriers in learning environments. To increase accessibility, reducing cognitive load is essential for people with learning and

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intellectual disabilities. Storytelling is a unique approach for addressing this issue as it provides structure, encourages reflection, and engages multiple sensory experiences that can enhance students' interest in learning. Especially in engineering courses where multiple abstract and difficult concepts are involved, storytelling holds the potential to engage students while facilitating knowledge transfer and application. This concept paper reviews and summarizes literature to highlight the benefits of utilizing storytelling as a pedagogical tool for neurodivergent students in engineering education. Further, it discusses subject-specific context where storytelling can be applied to improve the overall learning experience of engineering students overall, and why they may benefit neurodivergent students specifically.

1 INTRODUCTION

Preparing technically competent engineers for industry requires the internalization of technical knowledge and the development of strong visualization and critical thinking skills. Engineering education often involves abstract and challenging concepts that necessitate unique pedagogical approaches beyond traditional lecturing styles. Such pedagogical approaches, however, may not include methods that adequately accommodate the diverse learning needs of neurodivergent students.

Neurodivergent students are those classified as having neurological differences such as attention deficit hyperactive disorder (ADHD), autism spectrum disorder (ASD), and a variety of learning disabilities. Studies indicate that neurodivergent students pursuing university education, including engineering degrees, represent a small percentage of the total student population. Though retention and graduation rates of neurodivergent students compared to their neurotypical peers remains largely unknown, research also suggests that neurodivergent students generally graduate at lower rates (Chrysochoou et al. 2022). One possible reason for neurodivergent students' struggles in engineering are challenges in executive function related to working memory. Working memory is the executive function responsible for processing, storing, and recalling information and concepts (Smith et al. 2016). To promote inclusivity and improve the retention of neurodivergent students, it is critical to employ creative pedagogies that address diverse learning profiles, including those that may contend with working memory challenges.

The Universal Design for Instruction (UDI) framework is one proposed framework to address such needs by modifying instructional practices to be inclusive of all students. It aims to reduce the barriers posed by learning environments using nine principles (McGuire et al. 2003). We propose that storytelling, as a form of instructional scaffolding, can be an effective way to provide simple and intuitive instruction as presented by the UDI framework while allowing space to meet several more principles of the framework.

This concept paper proposes the use of storytelling in engineering education to support inclusive learning environments through informational scaffolding. Specifically, this paper explores the literature to investigate current applications of storytelling in higher education settings and its potential benefits for neurodivergent students specifically through the reduction of cognitive load and the principles provided by the UDI framework. Furthermore, practical suggestions will be provided for incorporating storytelling into engineering classrooms.

2 BACKGROUND

2.1 The Universal Design for Instruction

The UDI framework aims to implement principles of universal design into various aspects of instruction, such as the layout of physical spaces, curriculum design, and pedagogical practices, among other aspects. There are nine principles within this framework that guide its implementation. According to McGuire et al. (2003) those principles are:

- **Equitable use:** Designing instruction that accommodates and promotes access to people with varying abilities
- **Flexibility in use:** Instruction including a variety of methods that caters to a wide range of individuals' abilities
- **Simple and intuitive:** Designing instruction without the assumption of students' backgrounds, skillset or concentration level by simplifying concepts
- **Perceptible information:** Designing instruction in a way that is accessible regardless of the students' sensory abilities
- **Tolerance for error:** Instruction considers varying rates of processing information and levels of student background in prerequisite skills
- **Low physical effort:** Designing instruction in a way that maximizes attention and minimizes unnecessary physical effort
- **Size and space for approach and use:** Designing instruction in a way that considers appropriate size and space for use regardless of the student's body size, posture, mobility, and communication needs
- **A community of learners:** Designing learning environments that promotes student to student interaction and faculty-student communication
- **Instructional climate:** Designing instruction in a way that is welcoming, inclusive, and promotes high expectations from all students

2.2 Challenges Faced by Neurodivergent Students in Education

Neurodivergent students often face difficulties rapidly processing information compared to their neurotypical peers (Smith et al. 2016). This is primarily due to challenges in working memory, which is responsible for conscious cognitive processing. When working memory is overwhelmed it can lead to cognitive overload (Dahlstrom-Hakki and Wallace 2022). In neurodivergent individuals, they may have limitations in working memory capacity that make them more susceptible to cognitive overload. As a result, instructional modifications aimed at reducing cognitive load are beneficial for neurodivergent students.

Several techniques can be applied through various instructional methods to alleviate the demand on working memory including simple language during instructional activities, leveraging prior knowledge, incorporating informational scaffolding, and providing ample opportunities for review to decrease cognitive load at any single point in time (Smith et al. 2016).

3 STORY-TELLING

Storytelling is a universal mode of information transfer deeply ingrained in humans and can take various forms. It has been shown to enhance comprehension of concepts and mastery of skills through connecting components. Landrum et al. (2019) highlights the multiple ways in which storytelling may be beneficial in an educational setting. These include creating interest, providing a structure for remembering course material, sharing information in a familiar and accessible form, and establishing a more personal student-teacher connection. Its application has been observed in engineering courses (Ball et al. 2015), other STEM subjects (Anastasiadis et al. 2018), and at different educational levels.

In engineering education, storytelling has been used to strengthen analytical skills and highlight the relationship between multiple components in complex problem solving. Ball and colleagues (2015) compared the learning outcomes of youth apprentices who investigated a sustainability problem through digital storytelling and hands-on exploration. The findings indicated that the storytelling group achieved equal learning outcomes to the control group while demonstrating an increased understanding of the interconnectedness of various components of the sustainability problem. This suggests that storytelling can help establish a connection between concepts.

In another study, Anastasiadis and colleagues (2018) explored a collaborative approach to storytelling in secondary schools using a digital platform called STORIES. The collaborative nature of this method not only improved students’ understanding of the subject matter, but also enhanced their cooperative problem-solving skills. This finding is particularly valuable in STEM disciplines that require frequent collaboration. This study emphasizes the uses of storytelling as a collaborative and student-driven method of instruction.

Digital storytelling has also been used in undergraduate geography courses to promote deep learning, which involves the holistic integration of different facts. In a study conducted by Ryan and Aasetre (2021), students used digital story maps to enhance their understanding of geographical principles. The sequential structure of the stories facilitated a better grasp on concepts with temporal dimensions, such as the gentrification of an area. Students' reflections revealed a more concrete understanding of theoretical concepts as they applied them to real-life scenarios through the emotional impact of the stories.

These examples demonstrate the effectiveness of storytelling as an alternative or supplementary instructional approach, offering benefits beyond traditional methods of instruction for all students. As mentioned previously, for neurodivergent students specifically, the increased interconnectedness, real-life foundation, and guidance in cooperative problem-solving skills can help overcome challenges of executive functions.

3.1 How Storytelling Conforms with the Principles of the UDI Framework

Storytelling aligns with the principles of UDI, as evidenced by its diverse implementations and adaptability to different educational contexts. Whether stories are created by instructors or students, their application has been observed in geography courses, engineering apprenticeships, and secondary school science curricula. This flexibility, along with other notable features, enables storytelling to align with UDI principles. The alignment is specifically illustrated for the following six out of nine principles of UDI:

- **Flexibility in use:** Storytelling accommodates the needs of diverse learners by offering multiple methods of implementation. Instructor-generated stories have been explored (Landrum et al. 2019), while student-generated stories have been demonstrated on an individual or group level (Ball et al 2015, Anastasiadis et al. 2018, Ryan and Aasetre 2021). Such varied approaches highlight the potential for adaptable use in instructional settings.
- **Simple and intuitive:** Storytelling is a universal and familiar way of presenting information (Landrum et al. 2019, Bolkan 2021). The structure of stories enables students from different backgrounds and skill sets to comprehend the subject matter in an intuitive manner (Bolkan 2021).
- **Perceptible information:** Storytelling is delivered in various formats to cater to students' sensory abilities. For instance, the use of audio narration in digital story maps caters to both visual and auditory learners (Ryan and Aasetre 2021), showcasing the integration of different media in the storytelling experience.
- **Tolerance for error:** Storytelling can be adapted to account for varying rates of information processing and students' background knowledge. The content and

length of a story can be adjusted to accommodate students with different backgrounds of skills and knowledge.

- **Low physical effort:** Engaging in storytelling requires minimal physical effort for students, particularly when the story is generated by the instructor.
- **A community of learners:** Storytelling fosters collaboration when student teams work together to create stories, as observed in the study on the impact of the STORIES platform on collaboration skills (Anastasiadis et al. 2018). Furthermore, it facilitates interactions between faculty and students when they collaborate to generate story content for instructional purposes.

In summary, storytelling aligns with the principles of UDI by providing flexible approaches, simplicity, accessibility, adaptability, low physical effort, and opportunities for collaboration within the learning community. Its versatile nature allows for inclusive and effective instructional experiences for neurodivergent students and learners in general.

3.2 How Storytelling Provides Structure and Reduces Cognitive Load

Current research suggests that information conveyed through stories is often more easily understood since it is presented in a way that reflects how human brains naturally organize information – in a sequential structure (Landrum et al. 2019). This structure reduces the cognitive load of the listener allowing for easier comprehension of the information being conveyed (Bolkan 2021). Researchers argue that there may be neurophysiological reasons for which storytelling facilitates the learning process due to the involvement of characters in stories. These characters activate the listener's mirror neuron system, which allows them to simulate the experiences and emotions of the characters. As a result, the information becomes more engaging and memory retention is enhanced, facilitating the transfer of knowledge to new contexts (Landrum et al. 2019). Additionally, by using vivid and relatable examples, stories can connect and concretize abstract concepts that otherwise may be difficult to grasp (Anastasiadis et al. 2018, Ball et al. 2015, Ryan and Aasetre 2021). Bolkan (2021) notes that this is particularly beneficial for students who may struggle with more abstract or technical concepts, as stories can group these concepts in real-life context.

4 EXAMPLES OF STORYTELLING

The literature has shown two ways in which storytelling may be an effective instructional method for addressing the learning challenges faced by neurodivergent students in engineering. First, storytelling provides simple and intuitive instruction that naturally connects complex concepts and may be beneficial for many neurotypes, consistent with principles of the UDI framework. Second, storytelling reduces cognitive load by delivering information in a structured manner grounded in real-world contexts.

For instance, real-life scenarios can be effectively illustrated by using virtual experiments to study how a truss bridge deflects under different loading conditions. By applying narrative techniques to these virtual experiments, students are provided with context, promoting critical thinking and reflection based on their observations. This cause-and-effect relationship portrayed in the virtual experiment provides structures for students to understand the interconnectedness of concepts.

This could be taken one step further in augmented reality experiences. Augmented reality experiences can take the form of a storytelling journey, enabling students to explore and discover the progression of internal stresses in a loaded beam. This immersive approach could help students to develop an intuitive understanding of statistics and mechanics of material principles while processing information in a logical order.

Another example could be in the context of digital prototyping. Senior design projects provide a significant platform to showcase the evolution of a design from the initial stage to the final product. By employing computer-aided design (CAD) software in a land development project, students can iteratively design and explore various landscaping options for a given region. Incorporating a storytelling framework allows students to gain a comprehensive understanding of the roles of civil engineers, the design process involving permits, and the involvement of different stakeholders.

A final example could be a simulation-based scenario. In this scenario, a student could be asked to take on the role of a structural engineer for the seismic design of a building. This simulation would guide the student through the design and decision-making process to mitigate seismic hazards. Through the narrative style approach, students develop motivation and a sense of purpose by witnessing the practical implications of their decisions. Additionally, this provides students with a structure that they could replicate later in their professional engineering experiences.

5 IMPLICATIONS FOR ENGINEERING EDUCATION AND NEURODIVERGENT STUDENTS

Though these examples can be beneficial for all students, for neurodivergent students the additional structure of narrative techniques would be particularly helpful in organizing the necessary information and possibly help with later recall without causing cognitive overload. Using context heavy problems, while important for a richer understanding of engineering problems and later recall, can increase the cognitive load of neurodivergent students (Dahlstrom-Hakki and Wallace 2022). Providing the scaffolded structure of a story, and playing into a form of learning ingrained in the human psyche to form connection, may provide neurodivergent students with an avenue to navigate complex, context heavy problems with high cognitive demands.

While storytelling has been applied in diverse ways, there are still unexplored avenues in the research literature. As we have shown, storytelling can be a critical technique in the pedagogical arsenal of engineering education, creating relatable, reality-grounded scenarios that aid students in developing a deeper, more complex understanding of engineering topics. In the move towards diversifying engineering, engineering pedagogy must adapt to including diverse learning needs. We propose that the inclusion of storytelling in engineering education pedagogy will be beneficial to not only improving understanding of complex topics in engineering classrooms, but by increasing accessibility of these topics for neurodivergent students. By including pedagogical techniques that are accessible for neurodivergent students, we help students of many different backgrounds and needs.

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HOW DO TEACHERS RESPOND TO SUSTAINED CHANGE?

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Keywords: *engineering education, future learning, teacher competencies*

ABSTRACT

Higher Education is facing profound shifts. Employers seek graduates who can work effectively with others in rapidly changing contexts, defined by globalisation, diversity, digitalisation, climate change, complexity, a European war, and a recent global pandemic. The latter caused an instantaneous switch to online learning, where academics were forced to conduct their normally face to face classes through video conferencing tools. The calls for sustained change are challenging academics to rethink their traditional teaching roles and to develop new understandings of future-oriented learning methods and goals for their students.

This paper describes the research we have conducted into how academics have responded to these challenges, both short term (emergency remote teaching) and the long-term shift to new ways of teaching (e.g., for transdisciplinary learning working with diverse communities on their solutions). The authors have explored this issue over the last two years, using qualitative research methods, through workshops and interviews, which have been analysed for major themes.

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1 INTRODUCTION

1.1 Purpose

The purpose of this project was to hear a range of teacher voices, to understand the ways in which they are adapting to a rapidly changing world and how they are preparing students to work in this age of complexity. The project explored teaching insights and experiences during the COVID pandemic, as an example of future higher education challenges, to gain insights into the future directions of engineering education. Findings from this project can inform professional learning programs for academics at universities, to advance curriculum and teaching methods.

1.2 Purpose and Research Question

Our initial research focus was to explore how to develop the Deliberate Teacher's Voice in the Age of Complexity, Sustainability, Globalisation, Digitalisation and Transdisciplinarity. With deliberate we mean purposeful and with voice we mean a values-based identity [1]. To explore this idea, we needed to examine academic teachers' struggles and successes in finding their professional voice and why is this important now. The project was guided by three interrelated sub-questions:

1. What impact has COVID made to teaching perspectives of academics?
2. What are the big challenges in preparing graduates for their futures?
3. How is academic teaching adapting to these big challenges?

2 LITERATURE REVIEW

In 2019, when this project started, the Australian Council of Engineering Deans (ACED) was midway through a formal review of engineering education. The preliminary report highlighted the need for graduates to have a greater awareness of the social dimension of engineering, among other recommendations [2]. The final ACED report from 2021 [3] further recommended better **integrated curricula** (focused on development of professional skills), collaborative and open-ended problem-finding and solving in multidisciplinary project teams, greater emphasis on **digital design tools,** and stronger **industry** and **community** links in teaching.

There is also a long history of reviews of engineering education that have pointed towards the need for a broader skill set, greater awareness of the social context of engineering, more industry engagement, and more project-based learning [4-9]. Many papers have also explored the effects of emergency remote teaching imposed by the COVID pandemic, e.g., [10-12]. We incorporated this disruption into our study to see how the changes that COVID had forced on us might have opened academic minds to new ways of thinking about their teaching and the other big changes happening in the world, particularly climate change and the need for sustainability.

3 METHODOLOGY

3.1 Research Approach

To answer the research questions, a qualitative research paradigm was chosen as appropriate methodology; more specifically we adopted a philosophical hermeneutics approach [13], which blends phenomenological lived experiences and memorable moments with philosophical hermeneutics, a shared interpretation of perceptions. Philosophical hermeneutics contends that subjective experiences and perceptions need to be interpreted from different perspectives and not only from within the participant's assumptions, context, and background. A key feature of this approach is its question and answer dialogue between researcher and research participant, among the researcher team and with the literature [14]. The research was explorative seeking deeper and critical understanding of good teaching practices; it did not aim to be representational.

3.2 Research Design

The research design consisted of two phases. In phase 1, we conducted focus groups with European participants at the SEFI 2021 conference and Australasian participants at the AAEE 2021 conference (AAEE is the Australasian Association for Engineering Education). Because of COVID, we used zoom and breakout rooms. All three researchers were present and made field notes. In phase 2, we conducted semi-structured interviews with teaching academics at TU Berlin and UTS Sydney.

All interviews were recorded and transcribed. Six interviews were conducted face-to-face and three were conducted via zoom for convenience of the participants. Interviews were conducted with two or all three researchers, taking turns asking questions and writing fieldnotes.

3.3 Recruitment

For phase 1 we recruited conference participants via workshop abstracts that declared the research intent and our ethical conduct as approved by the Human Ethics Committee of UTS No. IML202103. 14 and 12 participants were recruited from the SEFI and AAEE conferences respectively.

For phase 2 we recruited nine consenting participants, five from TU Berlin and four from UTS via written invitations using relevant digital communication channels, for example in Teaching and Learning announcements, newsletters, and research networks. The research team was in no direct power relationship with participants. Table 1 (next page) provides brief demographic information of the research participants. For anonymity reasons, only broad demographic categories are provided.

The participants of the focus groups and the interviews covered a wide range of international, cultural, gender, and disciplinary backgrounds. We are aware that the answers and experiences are influenced and shaped by these various perspectives.

3.4 Data Collection

In phase 1 we described the current landscape of engineering education and then invited participants in small groups to respond to three questions:

1. In your opinion: which are the most crucial positive and negative changes in **your teaching** due to COVID?
2. What do you see as the future **big challenges your graduates** are facing?
3. What formats, topics and methods of **continuing education** would prepare you to become a **future-focused** academic teacher?

In phase 2 we collected teaching stories from interviewees using a semi-structured, in-depth dialogical approach following the hermeneutic tradition [14]. The intent of the interviews was to “gather manifestations of existing understandings” [14]. After piloting 19 questions we reduced them to six key questions to guide the conversation:

1. Tell us about your proudest moment as a teacher!
2. What matters to you as a teacher?
3. What are future trends or biggest ideas in your field?
4. What skills and competences will students need?
5. What does this mean for the teaching required into the future?
6. How do you create collaborative and inclusive classroom environments?

Table 1: Demographics of Phase 2 Participants

Number	Gender	Academic Rank	Institution
1	Female	Professor	TU Berlin
2	Female	Post-doc	TU Berlin
3	Male	Senior lecturer	TU Berlin
4	Male	Assistant Professor	TU Berlin
5	Female	Doctoral student/teaching assistant	TU Berlin
6	Male	Lecturer	UTS
7	Female	Associate Professor	UTS
8	Male	Associate Professor	UTS
9	Male	Associate Professor	UTS

4 WORKSHOP RESULTS

4.1 SEFI workshop (September 2021)

What were some of the positive and negative changes due to Covid?

Issues raised included a sense of urgency to adapt to a new online learning environment, despite sometimes little formal support from the university. There was a clear difference between those who are good at adapting and experimenting with different approaches and those who are reluctant to change. Teachers became overworked and tired, longing to go back to more personal interaction. Similarly, the social wellbeing of students came to the forefront, with more care and consideration required. This point also emerged in our later interviews.

What are the big challenges facing your graduates (beyond COVID)?

Participants mentioned lifelong learning, the need for more hands-on experiences, a greater emphasis on personal development, and limited transferable skills to new situations. This part of the conversation failed to engage with bigger issues such as climate change or complexity. COVID was simply all-consuming at this stage (2021).

What formats, topics and methods of continuing education would prepare you to become a future-focused academic teacher?

The discussion emphasised the need for course team approaches to management and structural barriers, including peer to peer learning, creating space to tell stories, to interact and to share experiences, learning in hybrid systems, working in teams, and experimenting together, and rethinking the conditions within which we must work as teachers, by setting up the right incentives.

Nevertheless, emphasis on more PBL has “helped to get teachers working more together”. Other suggestions included time for reflection and improved workload models.

4.2 AAEE workshop (December 2021)

Positive changes due to COVID?

There was a surprisingly quick move to online, which, before, most would have said was impossible. Industry-based projects worked well online because many of the industry partners were already remote (in Western Australia). Suddenly students realised they need to be able to work this way. Subjects had to be made more interesting and creative to maintain engagement by the students. The online environment also became quite personal – interruptions from children, etc – which added some light relief to teaching in the COVID era.

Negative changes due to COVID

Participants reported that online is just not the same and particularly hard on first year students. Engaging with each other online was more difficult with a loss of sense of community. The hybrid model (remote + face-to-face) was even very difficult; it was hard to pay attention to either the face-to-face group or the online group.

It was difficult for academic staff to create so much change in such a short time, particularly those who were not skilled in online tools. There was a lack of feedback from students (who often kept their cameras off), and a serious lack of hands-on experiences, particularly laboratories.

Changes for Students

Participants reported that there were many changes for students as well as for academics, e.g., students needed to find information for themselves, which changed the way they taught. Students were forced to adapt to change – some students have been in the same school since kindergarten – they need to learn how to learn and not just be taught. Students needed to develop the confidence to speak up in large online classes.

5 INTERVIEW RESULTS – THE BIG IDEAS

Five interviews were conducted at TU Berlin in June 2022 and four more were conducted at UTS in November/December 2022. Each interview lasted about an hour. The interviews were automatically transcribed using MS Word, with manual corrections. Each of the authors then read each of the transcripts, highlighting themes and quotations. Through our discursive process [13] we identified the following key themes:

1. Engineering as a social practice
2. Collaborative and interdisciplinary learning
3. Students as citizens
4. Student competencies
5. Academic teachers’ perspectives

5.1 Engineering as social practice

Engineering has social consequences; engineering and society co-create each other. Engineering lies at the intersection of the social sciences (human needs), technology design. Gender diversity is also a serious issue, because women have been poorly represented in engineering workforces, at least in Anglophone countries.

For engineers to solve social problems in context, programs need to be interdisciplinary and focus on social justice issues. Engineers deal with interdisciplinary problems in the world – literally between the disciplines. Interdisciplinarity and entrepreneurship are critical skills for the future, as problems become more complex and more interconnected.

> *"I'm particularly interested in the notion of justice-oriented citizenship. How young people grow up to be advocates for systemic change and the kinds of learning experiences that encourage the development of those" (Interview 1)*

5.2 Collaborative and interdisciplinary learning

If we are to develop student engineers with greater social awareness, we need to emphasise learning as a social process. A key shift in new learning environments is from listening to experts to encouraging students to speak up, to find their voice:

> *"[we] immediately start students talking (not listening) - finding their voice" (Interview 4)*

Recognising the messy social context in engineering can be confronting:

> *"This is like one of the … things that they write in the midterm reflection is there's so many new perspectives that I haven't seen and heard and even considered because what we arrange in our teaching is that they meet as equal and then they see that they are not equal in every respect." (Interview 4)*

Once students tune in to the social dimension of engineering, and learning in general, they see the importance of teamwork and collaboration:

> *"Learning design is fundamentally about relationships and those human centred skills of talking and understanding and communication; learning is and always will be a socially engaged endeavour." (Interview 5)*

This new style of classroom can be challenging for academics who see themselves as the expert:

> *"teachers need to be able to orchestrate the class and stop wanting to give the answers" (Interview 6)*

… and for students who bring a traditional learning approach from high school:

> *"[it's] best when students stop worrying about marks and focus on job outcomes" (Interview 9)*

Students need real projects, case-based learning, and discussion, to understand how to work in interdisciplinary teams. They need research-oriented teaching methods – asking questions and questioning assumptions.

COVID has boosted online education in a way we never anticipated. Students have discovered the flexibility that technology provides, particularly for senior students who are often juggling jobs and study (and sometimes families) as they finish their degrees. Students are shifting to online learning and skipping the face-to-face classes to suit their life commitments.

We are seeing greater use of technology to enhance collaboration, a key skill already identified. We are now all experts at online collaboration, helped by the maturing of multipurpose tools (e.g., MS Teams) in the last 3-4 years, supporting video and audio meetings, online forums, file sharing, project teams, plus a plethora of add-ins to support many other functions for team collaboration.

There was some scepticism of these technology trends. Nevertheless, AI is seen as a potential gamechanger:

> *"I think artificial intelligence is going to be significant, especially, but not limited to assessment." (Interview 9)*

… and education is becoming fragmented into smaller pieces (microcredentials), particularly in the postgraduate space:

> *"I think increasingly fragmented educational offerings are going to become the norm. I think learning will become more meaningful and more personalized." (Interview 6)*

5.3 Students as citizens

Interviewee 4 succinctly summed up this theme of students as citizens:

> *"[We are] developing students' critical thinking skills and their ability to think for themselves – communicate, communicate, communicate – that people can speak up for themselves and question their surroundings, that people start advocating for themselves and for others, and sustainability, and we want to produce democrats!" (Interview 4)*

The COVID crisis also helped academics recognise the need to care for students:

> *"Students learn in many ways; We need to care for our students … and for society; trust, flexibility, humour, responsibility … and humility." (Interview 1)*

We need to value the students and to help them to learn to transfer knowledge to new contexts:

> *"Empower your students; each of them is different, with different needs." (Interview 7)*

We also need to help students to take initiative and become confident thinkers and actors in the world (extending the social dimension already discussed):

> *"I want to see that they are able to take initiative to think about it by themselves, like what went wrong and what can I do?" (Interview 2)*

To do this, we need to create inclusive and enabling environments in our classrooms:

> *"I think the way to support that (critical thinking + communication) is through the environment of the course and through the space you provide, because in the end, it's important that everyone feels legitimated to speak and to speak up and to communicate." (Interview 2)*

5.4 Student competencies

Students need competencies in self-management, deep communication skills, through a shift towards independent learning (flipped classroom, online, potential impact of AI), all accelerated by COVID.

> *"[the] best students are quick thinkers, and they have outstanding communication skills. [They can] give good arguments to support their position; they are good team players." (Interview 3)*

We want curious and respectful students who engage in sustainability:

> *"questioning is an important skill - how to question things and cope with not having answers - example of 'blue engineering'; Students need to be curious. We need to emphasise process skills, less about content" (Interview 5)*

Students need new skills in areas such as data literacy. They need to know where to find information. They need to know the changes and dangers of new technologies.

Students need to be supported in the process of developing self-learning competence for lifelong learning as well as transferring previous knowledge and skills to new problems, tasks, and environments.

5.5 Academic teachers' perspectives

During COVID, the important goal of online teaching changed the role for academic teachers, focusing on facilitating learning:

> *"I think they know more than we know that they know. They learn from youth. They learn in other ways than we think they learn. They learn from you too. They learn from peers. They have different ways of learning. (Interview 1)*

In general, for teachers in engineering education to "teach the goals of projects and ask questions" is crucial as it encourages students to ask questions, use their own words, and work practically. Participants discussed a scaffolded approach to student learning:

> *"What have we learned now? And what can we do with it? And what can't we do with it? Ask questions about potential dangers of a technique we know the students know beforehand. [so that] they are not too surprised, or confronted" (Interview 3)*

Participants discussed their role as a facilitator of learning, and reducing power relations:

> *"One of the core questions in my teaching is power. What are the power relations … talk to someone else and immediately [they] started talking with other people because they were not there to listen only, but to speak with others … about many things." (Interview 4)*

Sensitivity and awareness for teachers is expressed through the learning environments they create:

> *"I think the way to support that is through the environment of the course and through the space you provide, because in the end, it's important that everyone feels legitimated to speak and to speak up and to communicate" (Interview 5)*

A new approach to **future challenges** in engineering education would be creating conditions for slow understanding of problems. Attenuating learning different technologies, and amplifying the ability to understand concepts behind principles and theories, and develop a prototype around these concepts:

> *"I think the competency development is most important. For me, I get very excited when I see … creative projects where a student has shown that they not only understand the standard methods for completing particular tasks but can actually … reinterpret the media and the methods that are described in new and interesting ways and show that mastery of those techniques. (Interview 9)*

A general approach to **future** engineering education is to go beyond producing materials and expanding students' knowledge:

> *“The most important thing is attitude to learn. So basically … I say ASK: A for attitude, S for skill, K for knowledge. So even if you don't have sufficient knowledge, you can acquire the knowledge through the skills. But then most important is the attitude. If you don't have attitude, then the skills and knowledge are useless.” (Interview 8)*

As a general perspective on aspects of learning independent of changing challenges and learning environments, *“learning is and always will be a social engagement” (Interview 6),* e.g., feedback, learning together all over the world in real time or simulation with AI:

> *“A lot of them go out and find other sources to check or to read against, or to investigate and I like that it shows broader interest than just showing up, so I guess, summing it all up, it's not about just showing up anymore, because you don't have to show up. It's about, you've actually got to do the learning.” (Interview 9)*

6 DISCUSSION AND CONCLUSION

In many ways, our observations are unsurprising. There was a clear message that engineering is a social practice and students need to understand the **social context of engineering**, through issues such as sustainability, climate change, globalisation, and so on. What was gratifying was the strength of convictions of some of our interviewees who saw this as both a professional mandate, an essential aspect of democratic citizenry, and a key role for themselves as educators.

An important outcome from COVID was the need to **care for students**, as well as to care for ourselves as academic teachers. This was an extension of the overall desire to educate excellent young professionals, with the confidence to speak up and to make positive change in the world.

Key **student competencies** were identified, particularly communication (including listening), teamwork, critical thinking, student confidence, and lifelong learning. Similarly, **academic competencies** were identified, e.g., the need to ‘orchestrate’ the classroom – be the conductor, not the instrumentalist. A future task is to take a closer look at the details of these different competencies, for teachers and learners, to confirm and to develop corresponding continuing education measures to support future-focused teaching and learning methods.

As we were analysing our interviews, a new disruption appeared on the horizon of teaching and learning environments with the free release of ChatGPT and other **generative artificial intelligence tools**. By some this is seen as changing the role of the academic teacher profoundly [15] raising questions about what needs to be taught and with what approach, affirming our project and findings. What it means to be human is at the centre of teaching and learning and of engineering.

Our findings reinforce the many **calls to action**, mentioned earlier, to transform engineering education to focus on the social context of engineering and student competency development, supported by new academic competencies for these new learning environments. Transforming how we see our students, and taking care of them and their career development, can change the nature of our curricula, as demonstrated by the examples in Lindsay, et al, [16].

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The stability of pre-enrolment prediction of academic achievement: criterion-referencing versus norm-referencing

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ABSTRACT

Positioning tests are organized in Flanders for prospective STEM students. They provide a low-stakes opportunity to assess their level of starting competences before enrolment. Predictive validity for subsequent academic achievement is an important quality measure of these positioning tests. However, the content of the tests varies over the years. This could be problematic for making accurate predictions based on data from previous years. Therefore, the objective of this study is to compare the stability over time of the predictions of academic achievement using either criterion-referenced (absolute grading) or norm-referenced (relative grading) positioning test grades of engineering and science students.

Comparisons of classifications over six academic years yielded various results (n=1258). For the engineering students, all predictions where unstable in those academic years when the tests were held online due to Covid-19 measures, and when positioning test participation became obligatory. However, in the years when aforementioned special events were absent, norm-referencing yielded the most stable prediction. For the science students, norm-referencing yielded a stable prediction over all six academic years, and criterion-referencing yielded a stable prediction when the tests were not held online. This clearly suggests that the implementation of norm-referencing in positioning tests may lead to more accurate predictions of academic achievement over time, regardless of changes in test content, despite the current use of criterion-referencing in practice.

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1 INTRODUCTION

Positioning tests are a low-stakes opportunity to assess starting competencies before the start of higher education for prospective students in a program in Science, Engineering, Technology or Mathematics (STEM). The tests are organized in the summer holidays between the end of Secondary Education and the start of Higher Education. This allows prospective students to remedy any shortcomings in starting competencies before their first semester starts or even reconsider their study choice, in case of a low score (Vandewalle, and Callens 2013, 1-2). Note that these low scorers are not prohibited from entering the study program, as is the case with a high-stakes entrance exam. STEM programs in Flanders have open admission to anyone with a secondary degree and there is no centralized exam at the end of secondary education. Positioning tests are an attempt at solving the resulting issue of heterogeneity of academic preparedness of Flemish freshmen STEM students. Research on predictive validity for academic achievement of positioning tests generally compares different parts of the tests, or different predictors (Pinxten et al. 2019, 45-66; Vanderoost et al. 2014, 1-8; 2015, 1-8; Van den Broeck 2019, 989-1007). Such research focuses on *which* predictors exist, but not *how* to use them in actual predictions. This study aims to address that gap, and to practically improve the positioning test procedure.

One prominent issue with predictions of academic achievement based in positioning tests is the stability of the prediction over multiple academic years. There is always a need to categorize pseudo-continuous data of positioning test scores in order to determine cut-off scores for providing feedback to students. In general terms, this comes downs to the question of what grade does a student need to pass the test? This question can be answered based on historical data, i.e. in order to have such a chance to obtain such academic achievement, a student needs at least such a score, based on data from previous academic years. However, an issue with such statements is that considerable variation between academic years could arise, either between (i) the level and content of the problems on the test, (ii) or between the level of competencies of the cohorts of students taking the test. Yet, the accuracy of such statements is essential for providing adequate feedback to students. Therefore, this study investigates the stability of classifications of academic achievement based on positioning test scores over six academic years, 2016-2017 to 2021-2022. The focus is on the programme of Engineering Technology (ET), as well as the cluster of programmes Chemistry, Biology, Biochemistry and biotechnology, Geography and Geology (CBBGG).

The ET positioning test contained 20 mathematics problems and 10 text problems from 2016-2017 until 2019-2020. From 2020-2021 onwards, the text problems were omitted and the mathematics part was expanded and split into 10 basic mathematics problems and 15 standard level mathematics problems. The former have the specific goal of identifying students with a high risk of low academic achievement and are of a lower difficulty than the latter, which are similar to the mathematics problems of 2016-2017 – 2019-2020. The CBBGG positioning test contained 20 mathematics problems, 10 text problems and 10 chemistry problems from 2016-2017 until 2019-2020. In this test as well, the text problems were omitted and the mathematics part was expanded to 10 basic and 15 standard level mathematic problems from 2020-2021 onwards. The text problems of the ET test and of the CBBGG test were different, but they remained the same over the years. The mathematics problems of the ET test were the same as the CBBGG test in each year, but they varied each year. Finally, the chemistry problems of the CBBGG test varied over the years as well. Additionally, participation to the positioning test became obligatory in 2021-2022 (meaning that students had to take the test in order to enrol, but they did not need a passing grade), and both the ET and CBBGG tests were held online in 2020-2021 due to Covid-19 restrictions. Both these ‘special events’ are potential threats to the stability of the classification, as they potentially changed the composition of the participating cohort (voluntary versus obligatory participation) and test taking behaviour.

The aim of this study is to compare criterion-referencing and norm-referencing in terms of the stability of their prediction of academic achievement. Criterion-referencing, criterion-referenced grading, or absolute grading is comparing the students’ skill against a predetermined standard, often half of the maximal score. Norm-referencing, norm-referenced grading or relative grading, on the other hand, means comparing the skill of the student to that of their peers. Criterion-referencing based predictions can be hypothesized as more robust against changes in participant population and test taking behaviour, while norm-referencing based predictions can be hypothesized as more robust against changes in test composition. Note that positioning test composition has changed on two levels: changes *of* test parts (i.e. entire parts were added and omitted) and changes *within* test parts (i.e. the problems within some parts changed each year). Currently, positioning tests use criterion-referencing for determining cut-offs.

The research question of this study is: does either criterion- or norm-referencing of positioning test (partial) scores yield a more stable classification of academic achievement over the academic years 2016-2017 until 2021-2022 for ET and CBBGG students?

2 METHODOLOGY

In total, 1258 students participated in the positioning test for ET or CBBGG in the six academic years between 2016-2017 and 2021-2022 and subsequently enrolled in the corresponding study program at KU Leuven, (see table 1).

Table 1. Overview of number of participants per test. [1]Test online due to Covid-19. [2]Participation obligatory.

	Study programme	
Year	**ET**	**CBBGG**
2016-2017	52	27
2017-2018	51	25
2018-2019	65	28
2019-2020	115	51
2020-2021	202[1]	47[1]
2021-2022	556[2]	39

First, a comparison of means of study efficiency after the first academic year (amount of ects credits successfully obtained divided by amount of ects credits the student enrolled for, expressed as a percentage), total test scores and partial test scores on standard mathematics and text was performed over the six academic years. Given non-normality of the data and small sample sizes in some cases, non-parametric Kruskal Wallis tests (Kruskal and Wallis 1952, 583-621) and post-hoc Wilcoxon (Wilcoxon, 80-83) tests with sequential Bonferroni-Holm correction for multiple comparison (Holm 1979, 65-70) were used.

For classification purposes, the pseudo-continuous variable study efficiency was categorized into two categories: (i) lower than 50 % and (ii) higher than or equal to 50 %. Given the aim of positioning tests to identify *at-risk* students (i.e. low achievers), the former category was regarded as ‘positive’. Categorized study efficiency was used as dependent variable. Independent variables used were total and partial test scores. A classification was performed for each independent variable and each academic year separately, and for multiple cut-off scores for the independent variables (see Figure 1a). Cut-off scores used were 7, 10, 12 and 14 for total score; 10 for partial score on standard mathematics; 5 on partial score on text. Afterwards, the classifications were repeated with percentile cut-offs of 20 %, 40 %, 60 % and 80 % for total score and 50 % for the partial scores.

Finally, in order compare the stability over the years of the classifications with score cut-offs (criterion-referencing) and percentile cut-offs (norm-referencing), contingency tables with number of true positive (TP), true negative (TN), false positive (FP) and false negative (FN) observations for each academic year were constructed separately for each value of cut-off and each test and test part (see Figure 1c) .These contingency tables were subjected to Pearson's chi-squared test to determine whether statistical differences between the years were present. Given the divergence of means of study efficiency and (partial) positioning test scores from 2020-2021 onwards, the analysis for classification based on total score was repeated for the first four years in the dataset.

Total population = P + N = PP + PN = TP + FP + FN + TN	**Predicted condition** **= positive (PP)** Students with a (partial) test score lower than the cut-off	**Predicted condition** **= negative (PN)** Students with a (partial) test score higher than or equal to the cut-off
Actual condition **= positive (P)** Students with a study efficiency lower than 50%	True positive (TP)	False negative (FN)
Actual condition **= negative (N)** Students with a study efficiency higher than or equal to 50%	False positive (FP)	True negative (TN)

(a)

(b)

Variable	2016-2017	...	2021-2022
True positive (TP)	TP 2016-2017	...	TP 2021-2022
True negative (TN)	TN 2016-2017	...	TN 2021-2022
False positive (FP)	FP 2016-2017	...	FP 2021-2022
False negative (FN)	FN 2016-2017	...	FN 2021-2022

(c)

Fig. 1. a) the confusion matrix based on classifications repeated for each academic year, test, test part, cut-off score and cut-off percentile. b) the formation of a contingency table based on data from the confusion matrices, repeated for each test, test part, cut-off score and cut-off percentile. c) an abridged contingency table (middle columns omitted) used for Pearson's chi-squared test.

3 RESULTS

Figure 2 shows boxplots and comparison of means over the academic year for ET and CBBGG students. The study efficiency of participating ET students is somewhat elevated in 2020-2021. In 2021-2022, the first year of obligatory participation, study efficiency drops again. Note that the study efficiency reported is that only of participants in the positioning test. Oppositely, the CBBGG study efficiency has a decline in 2020-2021. In terms of total test scores and standard mathematics partial scores, an increase can be observed for both ET and CBBGG students in 2020-2021, when the test was held online instead of on campus. Finally, despite the content not changing, a declining trend in partial text score can be observed for ET and CBBGG students over the four academic years with text problems on the test.

Table 2 reports the significance of the Pearson's chi-squared tests for contingency tables of the classifications based on total and partial positioning tests scores of ET and CBBGG students. All total score cut-offs for ET, both criterion-referenced and norm-referenced, yielded significant differences over the years. However, regarding only the first four academic years in the dataset, no norm-referenced cut-off yielded a significant difference. This indicates that the classification into study efficiency groups of ET students using norm-referencing was stable over the first four academic years. For CBBGG students, norm-referencing for total scores was stable over all academic years and both criterion- and norm-referencing were stable over the first four academic years. For ET students, only norm-referencing of partial text scores was stable throughout the academic years. Note that text was only part of the test in the first four academic years, where norm-referencing was also stable for total test scores. For CBBGG students, norm-referencing of standard mathematics and text partial scores were stable, while all criterion-referencing was unstable. Looking at the subset of data before the Covid-19 pandemic, both criterion- and norm-referencing of standard mathematics for both ET and CBBGG students was stable.

4 DISCUSSION AND CONCLUSION

The results show that norm-referenced positioning test score based predictions of academic achievement are generally more stable than criterion-referenced, regardless of any specific cut-off points or test parts. Even for predictions based on the text part, which did not change throughout the four academic years it was used, this conclusion holds. For CBBGG students, norm-referencing was stable throughout the entire six-year-period, despite the extraordinary online edition of the test in 2020-2021 due to the Covid-19 measures and consequent score inflation. For ET students, norm-referencing was only stable up until 2019-2020.

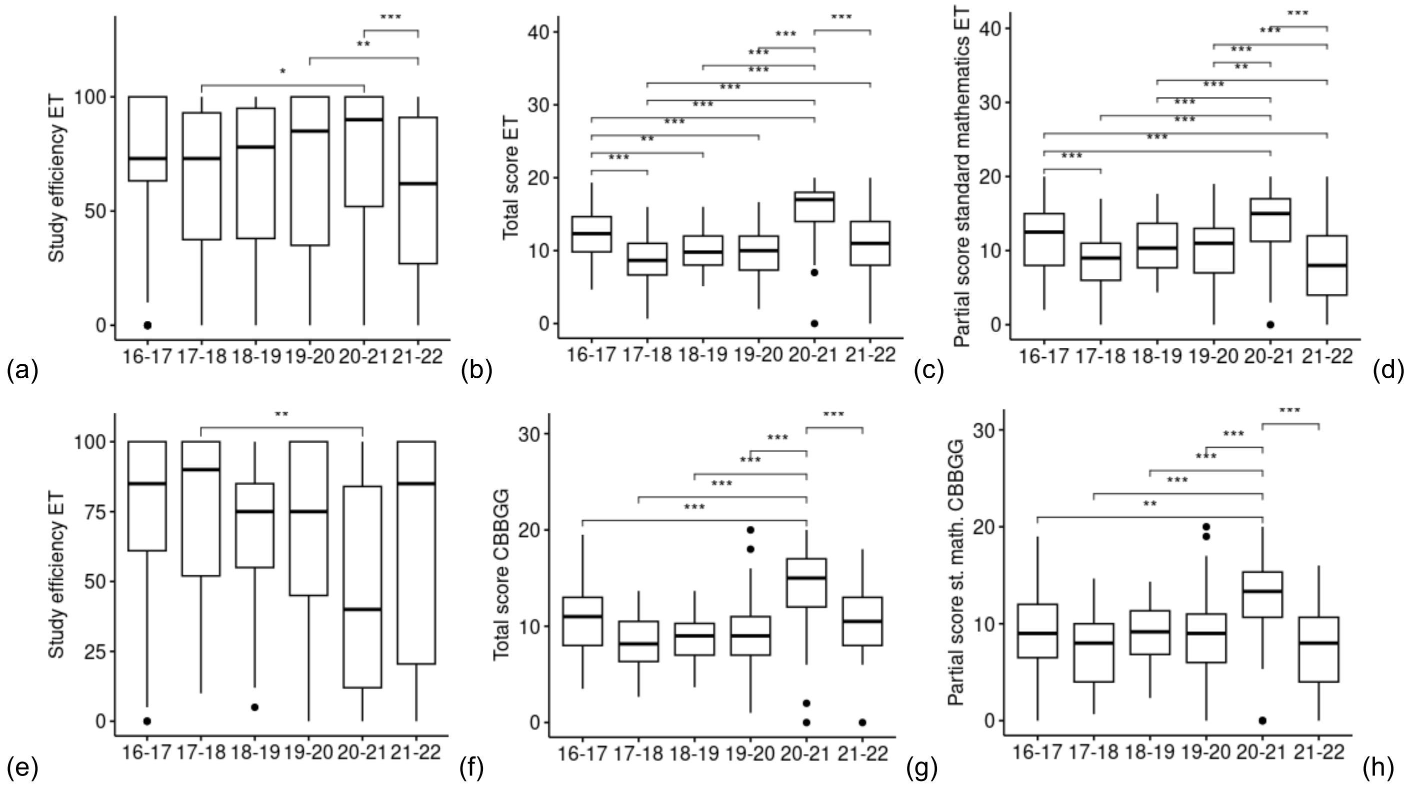
A likely explanation for this difference between CBBGG and ET is that besides Covid-19 measures, participation to the test became obligatory in 2021-2022 (yet results remained non-binding), which changed the composition of the population of participants. It is likely that before the obligation, more motivated students participated on average. It is to be expected that considerable changes in participant population affect the norm-referenced prediction. Another potential explanation for the difference between ET and CBBGG students is that the number of CBBGG participants is lower for each academic year. This means it is harder to find statistically significant evidence for instability which could lead wrong conclusions of stability. While this should be viewed as the most prominent limitation of our study, it does not undermine the conclusion that norm-referencing yields a more stable prediction than criterion-referencing.

Generally, there are considerable advantages of criterion-referencing as well: students deserve a grade that is ‘uncontaminated by reference to how other students in the course perform on the same or equivalent tasks’ (Sadler 2005, 178) and repeated criterion-referencing enables the tracking of progress (Lok, McNaught, and Young 2015, 455). While Lok, McNaught, and Young (2015, 461) state that there is no need for dichotomy between criterion-and norm-referencing, and both can be reported, the fact remains that if decisions for cut-off points need to be made based on historical data, one has to opt for either criterion-or norm referencing. The choice for which mixture of criterion- and norm-referencing is, of course context dependent and specific for each assessment procedure.

The discussion between criterion- and norm-referencing is also relevant for other assessment contexts in higher education. For example, the entrance exam for Medicine and Dentistry in Flanders switched from criterion- to norm-referencing in 2018 because the pass rates were too low before, yearly fluctuations in the number of students are undesirable and it is difficult to keep the difficulty level of the exam problems the same each year (Eggermont 2021, 3). Especially large-scale assessments where the emphasis lies on predictive validity, could benefit from norm-referencing.

In the case of determining cut-offs of positioning tests based on predictions with historical data, the findings of these study recommend using norm-referencing, given the more stable prediction of academic achievement based on norm-referenced positioning test grades, but only when no obvious changes in the population of participants can be expected. This recommendation does, however, not exclude reporting to students their criterion-referenced grade as well. Likely, Flemish students are more used to criterion-referencing, which means that reporting this as well, could increase interpretability of feedback, which is an important issue in the case of positioning tests (Hanssens et al. 2023, 1104). This reflects a specific advantage of reporting criterion-referencing without using it for determining cut-offs.

In conclusion, the decision to use criterion- or norm-referencing depends on the context and goals of the assessment, but reporting both types of grades can be considered to enhance the feedback to students and overall assessment procedure.



(a) (b) (c) (d)
(e) (f) (g) (h)

Fig. 2. comparison of means of a) study efficiency, b) total positioning test score, c) partial score on standard text for ET students and of e) study efficiency, f) total positioning test score, g) partial score on standard mathe Significance levels (: 0.05>p>0.01, **: 0.01>p>0.001, ***: p<0.001) of post-hoc Bonferroni-Holm corrected W corresponding lines. All Kruskal-Wallis tests were significant.*

	Study programme	Test part	Cut-off	Chi², significance (all academic years)	Chi², significance (2016-17 – 2019-20)
Criterion-referenced	ET	Entire test	7	***	n.s. (p=.29)
	ET	Entire test	10	***	**
	ET	Entire test	12	***	***
	ET	Entire test	14	***	n.s. (p=.15)
	ET	Math	10	***	n.s. (p=.17)
	ET	Text	5	/[1]	***
	CBBGG	Entire test	7	**	n.s. (p=.28)
	CBBGG	Entire test	10	***	n.s. (p=.31)
	CBBGG	Entire test	12	***	n.s. (p=.058)
	CBBGG	Entire test	14	**	n.s. (p=.16)
	CBBGG	Math	10	**	n.s. (p=.88)
	CBBGG	Text	5	/[1]	**
Norm-referenced	ET	Entire test	20%	***	n.s. (p=.45)
	ET	Entire test	40%	**	n.s. (p=.96)
	ET	Entire test	60%	***	n.s. (p=.28)
	ET	Entire test	80%	*	n.s. (p=.97)
	ET	Math	50%	**	n.s. (p=.85)
	ET	Text	50%	/[1]	n.s. (p=.63)
	CBBGG	Entire test	20%	n.s. (p=.069)	n.s. (p=.63)
	CBBGG	Entire test	40%	n.s. (p=.31)	n.s. (p=.84)
	CBBGG	Entire test	60%	n.s. (p=.23)	n.s. (p=.49)
	CBBGG	Entire test	80%	n.s. (p=.35)	n.s. (p=.84)
	CBBGG	Math	50%	n.s. (p=.11)	n.s. (p=.93)
	CBBGG	Text	50%	/[1]	n.s. (p=.26)

*Table 2. Significance levels of Pearson's chi-squared tests for contingency tables of classification based on total and partial positioning test scores of ET and CBBGG students. [1]Text was only part of the test in 2016-17 - 2019-2020. (n.s.: p>0.05., *: 0.05>p>0.01, **: 0.01>p>0.001, ***: p<0.001)*

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CONGRUENCE AND FRICTION BETWEEN TEACHERS' INTENTIONS AND STUDENTS' PERCEPTIONS OF CBL COURSES

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ABSTRACT

Challenge-Based Learning (CBL) has become specifically popular in higher engineering education as it embraces authentic, active, and interdisciplinary learning that requires students’ self-direction and collaborative decision-making. The CBL compass (van den Beemt et al. 2023) has been widely applied to capture the variety of educational innovations under the CBL label regarding their vision, teaching and learning, and support. As the tool only captures the teachers' intentions and goals, the question remains whether discrepancies occur with student perceptions of the CBL learning environment that may cause friction.

Therefore, this research project explored these discrepancies more thoroughly with teachers and students from CBL courses at four technical universities across Europe.

First, to understand the commonalities and differences between the courses, all courses were mapped with the CBL compass. Analyses of the outcomes showed that the courses varied regarding their implementation of the 36 indicators of CBL represented by the tool – most strongly regarding collaboration with internal and external stakeholders, assessment, and aspects of learning technologies, facilities, and support.

In the next step, we applied the student version of the CBL compass to understand student perception of these indicators and capture differences with teachers' intentions. The results mostly show a high agreement between teachers' intentions and students' perceptions. Friction arises in indicators regarding the complexity of the challenge, the involvement of external stakeholders, and the assessment. The results do not only help our understanding of student learning gains and experiences in CBL but may feed back into teachers’ CBL design processes.

1 INTRODUCTION

1.1 Challenge-Based Learning

Challenge-Based Learning (CBL) has explicitly become popular in higher engineering education (see Gallagher and Savage 2020; Doulougeri et al. 2021 for reviews) as it responds to calls for a more modern higher education that prepares students for the reality of later (professional) life in an increasingly complex and volatile world. One of these early calls suggested creating modern teaching and learning environments that use "representative authentic, real-life contexts that have personal meaning for the learners, and offer opportunities for distributed and cooperative learning through social interaction." (Dochy et al. 2003, 534).

Accordingly, CBL embraces authentic, active, and interdisciplinary learning that requires students' self-direction and collaborative decision-making. In the "absence of predefined study, content or challenge" (Gallagher and Savage 2020, 3), students learn "through identification, analysis, and collaborative design of a sustainable and responsive solution to a sociotechnical problem of which both the problem and outcomes are open. CBL at least involves (1) open-ended problems from real-world practice that require working in interdisciplinary teams, (2) entrepreneurial acting and design thinking, (3) combining disciplines, and (4) linking curricular and extracurricular activities. CBL deepens disciplinary knowledge and stimulates 21st-century skills such as self-awareness, self-leadership, teamwork, and an entrepreneurial mindset." (van den Beemt et al. 2020, 62). The phrasing of this definition already indicates that CBL implementation can vary considerably between contexts, depending on specific aims attached to this educational concept in the respective context.

1.2 CBL implementation

In order to capture the commonalities and differences of (possible) CBL implementations and show that the definition of the CBL educational approach may accommodate a large variety of set-ups, van den Beemt and colleagues (2023) developed the so-called CBL compass tool. With this instrument, CBL course designs can be examined based on three categories of dimensions (i.e., vision, teaching, and learning, support) and 36 indicators connected to 10 dimensions (e.g., the extent to which CBL experiments employ real-life open-ended challenges, refer to global themes, and involve stakeholders, aim at educating T-shaped engineers, employ self-directed learning, assessment, teaching, collaborative learning, interdisciplinarity, and learning technologies). Overall, the compass comprises 36 indicators representing the three dimensions and capturing the extent of their implementation.

1.3 Student perceptions of CBL implementation

The emphasis that the CBL educational approach places on student responsibility for their learning and teachers adopting a new role of learning facilitator and coach also leads to a demand for more vital collaboration between teachers and learners. This collaboration, however, naturally requires congruence of both parties' perceptions and interpretation of the learning environment, processes, and goals (e.g., Entwistle and Twait 1990; Vermunt and Verloop 1999). Könings and colleagues (2014) argued that “congruence between teachers’ and students’ perceptions of a learning environment is of central importance for an optimal teaching–learning process.” (p. 13) and incongruence, also called “friction” (Vermunt and Verloop 1999), may negatively affect student self-efficacy, intrinsic interest, commitment, and productivity. Using the *Inventory of Perceived Study Environment Extended* (IPSEE), Könings and colleagues (2014) found that “the majority of students experience substantial differences to their teachers’ perceptions” (p. 17). Specifically, students with the least shared perceptions with teachers reported more motivational and affective problems and less constructivist conceptions of learning, consequently performing worse than other students (p. 27).

While Könings and colleagues have not focused on CBL in higher education but in secondary education, the findings are relevant for CBL research and practice. The course design and implementation of CBL courses are the results of a design process the teacher goes through. Given that CBL is a student-led approach, with students being the central agents in CBL courses, their perceptions of CBL design characteristics are more relevant, and mismatches between teachers' intentions and students' perceptions of the course may cause even more substantial friction in the teaching and learning process.

1.4 Research Questions

Consequently, this research project explored these discrepancies in more detail with teachers and students from different CBL courses at various European technical universities.

Research Questions were:

1) How do teachers (intend to) implement the CBL courses?
2) How do students perceive the implementation of the CBL courses?
3) Do students view…
    a. differ from teachers’ intentions? And
    b. vary among students of the same course?

2 METHODOLOGY

2.1 Procedure and instruments

This research was approved by the collaborating universities' institutional review boards. In a first step, to understand the commonalities and differences of the courses, CBL courses that were part of the EuroTeQ Collider (see 2.2) at four different universities were mapped with the CBL compass (van den Beemt et al. 2023). In order to do so, interviews with the responsible teachers of each course took place right at the beginning of the course, during which the respective course was rated on each of the above-described indicators of the CBL compass tool using a 4-point Likert scale. The comparison of teachers' intention and students' perception focuses on indicators describing the extent CBL courses use real-life and open-ended challenges ("theoretical/abstract" to "real-life"), refer to themes ("no focus" to "full focus"), stimulating interdisciplinary teamwork ("not implemented" to "fully implemented") and the assessment during CBL ("imbalanced" to "fully balanced") as well as involving stakeholders ("no collaboration" to "full collaboration"). Furthermore, general information about the course implementation was collected (e.g., student numbers, course schedule, and set-up).

In order to capture student perceptions of the same courses, students are surveyed with the *student compass*. This tool has an analogous setup to the CBL compass. However, it has been adapted to the student's perspective, has recently been developed at Eindhoven University of Technology, and relevant indicators for answering the research questions were chosen. In a standardized questionnaire, students also rated the implementation of the indicators described above on a 4-point Likert scale. Data collection was scheduled in the middle of the course (depending on the respective timeframe) to ensure students had already gained ample experience to rate the indicators of the compass. Data collection took place between April and June 2023.

2.2 Sample

Teachers and students from CBL courses at four technical universities across Europe were invited to participate in this research. Courses varied in the number of coaches, participating students, timeframe, etc. The duration of the CBL courses varied from an intensive one-week course (University 1 – course 1) to eight-week courses (University 3 and 4 – courses 3 and 4) and a longer sixteen-week course (University 2 – course 2). All courses were open to different study levels and study programs. As the courses were part of the EuroTeQ Collider, a joint European CBL format, the courses shared comparable learning goals and an overarching theme for the challenges.

Due to the varying implementation status of courses, student response rates differed per course. Table 1 provides an overview of student samples per course.

Table 1. Student samples per course

	# students	gender			Study level			Field of study				
		m	*f*	*d/na*	Bachelor	Master	PhD	E	I	B	S	O
Course 1	13	3	9	1	10	2	-	5	6	-	-	5
Course 2	6	2	6	-	-	5	1	-	3	-	1	1
Course 3	9	8	1	-	4	5	-	6	2	1	2	-
Course 4	27	19	7	-	-	26	8	8	1	11	6	7

Notes. Field of study: E = Engineering, I = Informatics and computer science, B = Business and Economics, S = Social Science, O = Other. The selection of more than one study program was possible.

3 RESULTS

3.1 Teachers' intentions for CBL courses

Unanimously, teachers indicated that the challenges students worked on in their courses were real-life/authentic, open-ended, complex, and interdisciplinary, focusing on transforming business as usual and creating societal impact (see Table 2).

Regarding the last indicator of the *Vision* dimension of the CBL compass, the variance between courses could be identified with teachers reporting varying degrees of challenge owners and stakeholder involvement: some involving external challenge owners (e.g., from industry, government, or culture) and stakeholders, others only working with internal experts).

Also, the teachers' ratings reflect the variety in the implementation of the assessment. While a balance between product and process are stated for course 1 and 3, teachers responsible for course 2 and 4 described the implementation as somewhat balanced.

Regarding the last dimension of the CBL compass, namely the *Facilities and Support* available to teachers, courses showed a large variety. While all teachers indicated that adequate spaces were available for their courses, this was only sometimes true for the required materials and tools. Support structures for course design, pedagogical support, and developing coaching skills were also perceived to be available to varying extents (fully available at one university to unavailable at other universities).

3.2 Students' perceptions of CBL courses

Summarizing the descriptive results presented in table 2, students who participated in the CBL courses emphasized the interdisciplinarity of the challenges and, accordingly, a need for interdisciplinary knowledge from different subjects for their teamwork. Besides this, the challenge was perceived by students to support both individual and teamwork and as authentic by focusing on real-life problems.

Regarding assessment, students reported that there was a balance between the assessment of product and process as well as formative and summative assessment.

Differences in student responses could be found regarding the perceived (long-term) societal impact and the involvement of external stakeholders as challenge owners (e.g., course 2: $M = 2.50$, $SD = 1.05$; course 4: $M = 3.69$; $SD = .55$).

When focusing on the variance between responses of students of the same course, especially for the CBL course at University 2 (course 2), a higher variance could be found in how students rated the authenticity of the challenge ($M = 3.50$; $SD =.123$). For course 3, the balance between individual and team learning during the assessment also showed a higher variance ($M = 2.67$; $SD = 1.23$). Further results can be found in table 2.

Differences in students’ perceptions, even those attending the same course, may arise from them working in smaller groups on different challenges within and between the courses.

Table 2. Comparison of teachers' intentions and students' perceptions of CBL courses

Indicator	Course 1			Course 2			Course 3			Course 4		
	Teacher	Students		Teacher	Students		Teacher	Students		Teacher	Students	
		M	SD		M	SD		M	SD		M	SD
Real-life and open-ended challenges												
Real-life/ Authenticity	4	3.15	.81	3	3.50	1.23	4	3.56	.53	4	3.73	.67
Open-endedness	4	3.00	1.08	3	3.67	.52	4	3.76	.50	4	3.46	.58
complexity	4	2.77	.83	4	2.50	1.00	4	3.56	.53	4	3.31	.84
Interdisciplinarity	4	3.08	.76	3	3.67	.52	4	3.33	.71	3	3.62	.50
Global themes												
Long-term societal impact	4	3.00	1.00	2	3.50	.55	3	3.56	.73	4	3.62	.57
Collaboration with stakeholders												
Challenge-owner	4	2.97	1.04	3	2.50	1.05	3	3.67	.50	3	3.69	.55
External stakeholders	4	2.77	.60	2	3.33	.82	3	3.22	.67	3	3.50	.51
Assessment - Balance												
Product - process	4	3.23	.60	2	3.17	.41	3	3.11	.33	2	3.42	.50
Individual - team	4	3.08	.76	3	3.33	.52	3	2.67	1.23	3	3.42	.64
Formative - summative	4	3.00	.58	3	3.00	.00	4	3.33	.87	2	3.50	.51
Interdisciplinarity												
Interdisciplinary teamwork	4	3.38	.65	3	3.17	.41	4	3.33	.87	3	3.58	.50
Combinations of individual and teamwork	4	3.33	.63	3	3.50	.55	4	3.44	.53	3	3.65	.49
Notes. Teachers Compass: Min. 1, Max 4; Students Compass: Min. 1; Max 4 (1=strongly disagree; 2=disagree; 3=agree; 4=strongly agree)												

3.3 Congruence and friction

Generally, congruence between students’ and teachers’ perceptions of implementing the CBL courses is relatively high. Based on the results described above, congruence could be identified in teachers' and students' evaluations that the courses use real-life open-ended challenges that require interdisciplinary knowledge and collaboration.

For courses 1 and 2, friction arises concerning the complexity of the challenge. In addition, for course 2, students rated the long-term societal impact higher than teachers. Also, students from courses 2 and 3 show higher agreement for the balance of product and process, individual and team learning, and formative and summative assessment than expressed by interviewed teachers. Also, the balance between formative and summative assessment is rated higher by students in course 4.

4 DISCUSSION AND OUTLOOK

Results from the teacher interviews showed that when implementing the CBL courses, the focus was on the complex, authentic, real-life challenges and the interdisciplinary nature of the challenge and cooperation. Lower scores are reported for assessment, especially for courses 2 and 4 (Research question 1). Students' evaluation of the learning environment also emphasized the implementation of the characteristics mentioned above but showed lower scores for collaboration with external stakeholders and the complexity of the challenge for courses 1 and 2 (Research question 2). We can only hypothesize that this may arise from difficulties in implementing the course and the availability of stakeholders and experts during the work process. In future research, this could be followed up by conducting retrospective evaluation interviews with the respective teachers.

From the high convergence of the student and teacher ratings in the CBL-Compass tool, it can be deduced that both perceive the learning environment and the implementation of the CBL courses in a comparable way (Research question 3), which according to the findings of Könings and colleagues (2014), will benefit student motivation, engagement, and performance in these courses.

Future research will further focus on student learning in CBL courses, trying to understand what type of students are attracted by such courses and whether these students are more open to such new educational approaches and, thus, more perceptive of teachers' intentions. Also, the relationship between the indicators and student engagement and motivation will be researched.

Practical implications include reflecting on collaboration with external stakeholders and transparent communication on the complexity of the challenge and assessment between students and faculty. Furthermore, insights into student learning outcomes in differently designed CBL courses may help the development of the CBL educational approach at different technical universities across Europe, course implementation, and, above all, educational collaboration.

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ADDRESSING CHALLENGES OF THE SDGS: STAKEHOLDER PERSPECTIVES ON SKILLS REQUIRED BY ENGINEERING STUDENTS ON THE ISLAND OF IRELAND

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ABSTRACT

Living sustainably on a shared island poses both challenges and opportunities for engineers of the future. Whilst at a European level, the professional skills that engineers will need to achieve Sustainable Development Goals (SDGs) have been identified, less has been written on how these skills should be contextualised for a national, regional and/or local level. This research paper considers the specific professional skills required for engineers on the island of Ireland. It examines differing perspectives of stakeholders, comparing and contrasting views according to local context (Northern Ireland (NI), Ireland).

A professional skills survey was designed, drawing on previous research which had identified 53 competences in six sets (Fundamental Technical Skills, Application Skills, Outward Facing – People Orientated Skills, Inward Facing – Ways of Thinking, World View, Character and Ethical Orientation). The survey was completed by 235 academics, students and engineering employers (ranging from SMEs to large multinationals) on the island of Ireland in 2022. Analysis highlighted interesting similarities and differences in stakeholder perspectives between the two jurisdictions. Whilst awareness of SDGs was markedly higher in Ireland compared to NI, average importance ratings for many competences were generally similar in both jurisdictions.

These findings have improved engineering educators' understanding of the stakeholder perceptions including how those vary by location. Such improved understanding, including regional insights, should help to inform engineering curriculum development at tertiary level and ensure that engineering graduates are equipped with the appropriate skill set to contribute solutions to the big global challenges of our day.

1 INTRODUCTION

1.1 Geographic Context: One Island, Two Jurisdictions

Life on a shared island, in particular the island of Ireland (comprising Ireland and Northern Ireland), presents both challenges and opportunities, including within the realms of sustainable development. Whilst Ireland is one of 27 member states of the European Union (EU) (an economic and political union), Northern Ireland (NI) is a constituent country of the United Kingdom, which is no longer a member of the EU. Operating within two jurisdictions (each of which has its own governance arrangements and legal frameworks, as well as professional engineering institutions), engineers of the future will be tasked with addressing problems that are indifferent to such boundaries.

Considering the pipeline of future engineers, it is important to note some key differences in typical pathways to university. In both jurisdictions, education is compulsory up to 16 years old. In Ireland, students wishing to enter the university system take the Leaving Certificate State examination at the end of the senior cycle (aged 17 or 18). They typically take seven Leaving Certificate subjects which must include English, Mathematics and Irish. Places on university courses are allocated according to a points system (top six subjects scored for each student). In NI, at the end of compulsory education (16 years), students take GCSE examinations, usually in eight subjects including English and Mathematics. Those who continue in education study for a further two years, either for A-levels (typically three (sometimes four) subjects, graded by letter, and all considered in university admission process) or vocational courses, in schools or further education colleges. Thus NI students entering university will have a more focused in-depth subject range compared to students from Ireland with a broader range of subjects.

The professional skills that engineers will need to achieve Sustainable Development Goals (SDGs) have been identified at a European level (Beagon et al, 2022). However, contextualising these to a smaller scale (national, regional and/or local level) is the focus of this paper. It explores stakeholder perspectives on the specific professional skills required for engineers on the island of Ireland, within the context of achieving the SDGs. It examines the extent to which these perspectives vary according to local context (NI and Ireland).

1.2 Literature Review

Previous research studies undertaken into the generic skills that engineers require have been generally conducted at a national or international level (Passow and Passow 2017; Male et al. 2011; Kovesi and Csizmadia 2016; Colman and Willmott 2016). Seminal work on skills requirements for sustainable development in particular highlighted a range of competences that are needed for a sustainable future (Wiek et al. 2011; de Haan 2010; Rieckmann 2012). More recent work as part of an Erasmus+ project (A-STEP 2030) focused more directly on competence requirements specifically for engineers in order to work towards achieving the SDGs (Beagon et al, 2022). The study used focus groups with engineering employers, engineering academics and engineering students in four European countries to collect and synthesise their views on the key competences required. The findings highlighted 53 separate competences presented in six main categories (Fundamental Technical Skills, Application Skills, Outward Facing – People Orientated Skills, Inward Facing – Ways of Thinking, World View, Character and

Ethical Orientation). The research also identified that there was a lack of agreement on which competences should be prioritised.
The UNESCO (2017) report “Education for Sustainable Development Goals: Learning Objectives” provides a framework for educators to enhance their curriculum, offering students an opportunity to develop the much-needed skills required of the future. However, it is not surprising that educators could feel overwhelmed faced with a list of 53 competences and hence, contextually relevant priorities for a local context could prove useful in focusing educational initiatives in individual Universities.

2 METHODOLOGY

2.1 Context for the Research

This research was conducted as part of a Higher Education Authority (HEA) funded project entitled PROFESS 12. One of the project aims was to design and test an innovative Summer School to help students develop skills to solve SDG 12. A survey was circulated as a pre-cursor to the design of the Summer School to ascertain appropriate teaching activities according to the localised and prioritised skill set requirements of survey respondents on the island of Ireland.

2.2 Approach

A professional skills survey, developed using MS Forms, was based on previous research (Beagon et al, 2022) which identified (at a European level) the skills engineers need to meet the SDGs. Ethical approval for the survey was granted by the Research Ethics and Integrity Committee in TU Dublin (REIC-21-74); the survey was piloted prior to launch in November 2022. The survey requested information on respondent profile capturing characteristics such as category (academic / employer (including sector and size) / student (including year)) and demography (gender, age, region). The first question seeking stakeholder perceptions investigated awareness of the SDGs using a 5-point Likert scale. Further questions sought ratings on importance, preparedness of engineering students and graduates and then priorities for teaching in reference to the 53 competences identified in six competence sets (Beagon et al, 2022). An open text response was provided for additional feedback (if any). Invitations to complete the survey were issued (primarily via email) to:

- **students** in TU Dublin and Ulster University (UU)
- **academics** in the research team’s personal networks (wider than TU Dublin and UU)
- **engineering employers** in the research team’s personal networks and through professional institutions (such as Engineers Ireland (EI) and Institution of Structural Engineers (IStructE)).

This paper describes the findings in relation to awareness of SDGs and the importance of the competences only. Analysis of survey responses by region has been undertaken. It does not differentiate by gender, category (employer, educator, student) nor by size of employer though we recognise that views are likely to differ within some, if not all, sub-groups. This could form the basis of further analysis.

3 FINDINGS

3.1 Profile of respondents

There were 235 respondents to the survey from the island of Ireland; around twice as many men as women responded (overall and within the two jurisdictions). Just over one third of responses were from NI, with the majority from Ireland. Overall, more than half of responses were from students (129, 54.9%) with similar proportions from academics (54, 23.0%) and employers (52, 22.1%) respectively. A small number of responses (n=7) from elsewhere were excluded from this analysis.

3.2 Awareness of SDGs

The first question gauged **awareness of the SDGs** on a 5-point Likert scale. Average scores are shown in Table 1.

Table 1. Awareness of SDG
(5 – Extremely Aware to 1 – Not at all Aware)

	NI	**Ireland**	**All Island**
Number of respondents	88	147	235
% of respondents	37.4%	62.6%	100%
Awareness of SDGs (average score)	2.7	3.5	3.2

Overall, whilst the average level of awareness was **3.2** (*somewhat* to *moderately aware*), unpacking this reveals marked differences. The level of awareness in Ireland, 3.5 (between *somewhat* and *moderately aware),* is considerably higher than awareness in NI of 2.7 (closer to *somewhat aware*).

3.3 Importance of Competences

For 53 competences in six Competence Sets, respondents rated **importance** on a 5-point Likert scale, with 5 being very important and 1 not important. For reference, the competences included in each set are (Beagon et al. 2022):

- **1 Fundamental Technical Skills** (Mathematics Skills, Digital Skills, Economic Skills, Research Skills, Technical Skills);
- **2 Application Skills** (Multidisciplinary Skills, Problem Solving, Design Skills, Interpretation Skills, Conceptual understanding, Resources optimisation, Innovation, Entrepreneurship, Decision Making Skills, Learning to Learn, Project Management, Organisation Skills, Problematisation (to consider or treat as a problem));
- **3 Outward Facing – People Orientated Skills** (Intercultural Skills, Collaboration, Leadership, Conflict Management, Negotiation, Communication, Respecting Diversity, Teamwork);
- **4 Inward Facing – Ways of Thinking** (Critical Thinking, Life Cycle Thinking, Holistic Thinking, Systems Thinking, Creativity, Analytical Thinking, Stress Management, Time Management, Self-Reflection, Multi-perspective Thinking);
- **5 World View** (Global Awareness, Social Responsibility, Challenging the status quo, Sustainability Awareness, Environmental Awareness, General Knowledge, Lifelong Learning);

- **6 Character and Ethical Orientation** (Respect for others, Open Mindedness, Agility, Adaptability, Curiosity, Empathy, Emotional Intelligence, Perseverance/Grit, Ethical Conscience, Personal Engagement).

All 53 competences are rated as being of at least some importance: average ratings for all are **at least 3.0**. The **five most important competences** overall are: Problem Solving, Communication, Teamwork, Respect for Others and Critical Thinking. All have similar ratings, between 4.56 and 4.74.

Disaggregating results by region yields broadly similar findings. The **top five most important competences** overall are also top five in NI and Ireland, although there is slight variation in rank order and average importance. Problem Solving, rated 4.75, is the most important competence in NI, whilst Communication (also 4.75) is highest in Ireland, as shown in Table 2.

Table 2. Average Importance Ratings by Competence and Jurisdiction (5-Extremely Important to 1-Not at all important)

Rank	Northern Ireland	Ireland	All Island
	Top 5 most important – average importance		
1	Problem Solving, 4.75	Communication, 4.75	Problem Solving, 4.74
2	Respect for Others, 4.64	Problem Solving, 4.73	Communication, 4.68
3	Communication, 4.57	Teamwork, 4.69	Teamwork, 4.64
4	Teamwork, 4.56	Critical Thinking, 4.61	Respect for Others, 4.60
5	Critical Thinking, 4.48	Respect for Others, 4.59	Critical Thinking, 4.56
	Bottom 6 least important – average importance		
48	Intercultural Skills, 3.82 **Negotiation, 3.82**	Intercultural Skills, 3.96	Challenging the status quo, 3.93
49	n/a	**Agility, 3.95**	Intercultural Skills, 3.91
50	Challenging the status quo, 3.80	Holistic Thinking, 3.78	General Knowledge, 3.82
51	Economic Skills, 3.72	General Knowledge, 3.76	Holistic Thinking, 3.74
52	Holistic Thinking, 3.67	Economic Skills, 3.74	Economic Skills, 3.73
53	Entrepreneurship, 3.47	Entrepreneurship, 3.22	Entrepreneurship, 3.31

The **range of average importance ratings** (all respondents on the island of Ireland) is **1.43.** Both lowest (Entrepreneurship, 3.31) and highest (Problem Solving, 4.74) competences are in Competence Set 2. However, the Entrepreneurship rating is an outlier: the next nearest competence has an average importance rating some 0.42 points higher (Economic Skills, 3.73). Excluding the outlier reduces the range to **1.01**. Thus, average importance ratings for all competences are closely grouped.

Average importance ratings of competences are fairly tightly grouped, as shown by considering the **range** of ratings (excluding Entrepreneurship, the outlier):

- **1.08 in NI**: from 3.67 (Holistic Thinking) to 4.75 (Problem Solving);
- **1.01 in Ireland**: from 3.74 (Economic Skills) to 4.75 (Communication).

Entrepreneurship, the least important competence in both jurisdictions, is rated somewhat lower in Ireland (3.22) than in NI (3.47). Three other competences (Economic Skills, Holistic Thinking, Intercultural Skills) also appear in the bottom six in both jurisdictions; rank order and average importance vary slightly.

Turning to Competence Sets, examining average importance ratings along with lowest and highest average importance ratings reveals more about similarities and differences between the two jurisdictions. In fact, they demonstrate a lot of similarity as shown in Table 3.

All six Competence Sets have average importance ratings above 4.0 highlighting a substantial degree of importance ascribed to all. In NI ratings range from 4.07 (Competence Set 5) to 4.25 (Competence Set 6); in Ireland from 4.14 (Competence Set 2) to 4.26 (Competence Set 6). In five Competence Sets, the average importance rating is marginally higher (though by no more than 0.14) in Ireland than in NI, the exception is Competence Set 1 (0.03 higher rating in NI).

In four of six Competence Sets, the same competences are rated lowest and highest in both jurisdictions, though ratings differ slightly. However, in Competence Set 3, two competences tie for lowest rating in NI: Intercultural Skills and Negotiation Skills, whereas only the former appears as Ireland's lowest rated competence. Furthermore, the lowest rated competences in Competence Set 5 differ as do ratings: Challenging the Status Quo (3.80) in NI and General Knowledge (3.76) in Ireland. In Table 3, competences in red font illustrate differences between NI and Ireland, showing those rated lowest in one but not in the other.

Table 3. Importance Ratings by Competence Set and Jurisdiction
(5-Extremely Important to 1-Not at all important)

Competence Set (Number of Competences)	**Northern Ireland** **Average score per set** **Lowest and highest rated individual competence**	**Ireland** **Average score per set** **Lowest and highest rated individual competence**
1 Fundamental Technical Skills (5)	Average (4.21) Economic Skills (3.72) Technical Skills (4.45)	Average (4.18) Economic Skills (3.74) Technical Skills (4.45)
2 Application Skills (13)	Average (4.09) Entrepreneurship (3.47) Problem Solving (4.75)	Average (4.14) Entrepreneurship (3.22) Problem Solving (4.73)
3 Outward Facing – People Orientated Skills (8)	Average (4.17) {Intercultural Skills (3.82) {Negotiation (3.82) Communication (4.57)	Average (4.30) Intercultural Skills (3.96) Communication (4.75)
4 Inward Facing – Ways of Thinking (10)	Average (4.10) Holistic Thinking (3.67) Critical Thinking (4.48)	Average (4.20) Holistic Thinking (3.78) Critical Thinking (4.61)
5 World View (7)	Average (4.07) Challenging the status quo (3.80) {Sustainability Awareness (4.34) {Environmental Awareness (4.34)	Average (4.21) General Knowledge (3.76) {Sustainability Awareness (4.54) {Environmental Awareness (4.54)
6 Character and Ethical Orientation (10)	Average (4.25) Agility (3.93) Respect for Others (4.64)	Average (4.26) Agility (3.95) Respect for Others (4.59)

For the majority of competences (39 of 53), average importance ratings for Ireland are higher than for NI: the opposite is true for the other 14. However, whilst there are some differences between average importance ratings (and corresponding ranking) for competences in NI and Ireland, these are typically quite small (largest magnitude difference is 0.32).

4 SUMMARY AND ACKNOWLEDGMENTS

There are moderately high **levels of awareness of SDGs** amongst respondents, with an average rating overall of 3.2; awareness is markedly higher amongst respondents in Ireland compared to NI. The impact of this finding indicates that there is scope to raise awareness further, particularly in NI and this can be immediately addressed in the design of engineering programmes.

All competences are rated as being of at least some importance with **average importance ratings** above 3 (out of 5) though there is considerable variation across the 53 competences. It is worth noting that the **five most important competences** are the same overall and within each jurisdiction, which suggests that amongst survey respondents in both jurisdictions there are similar perceptions on competences required of engineers.

Disaggregating results into the two jurisdictions shows that whilst some differences exist, these are generally small. Competences are typically rated at similar levels though respondents from Ireland tend to rate importance marginally higher than those from NI: this is the case for 39 of 53 competences. This translates into similarities at Competence Set level. The similarity in ranking of importance of the competences is perhaps surprising to some extent given some differences in the two jurisdictions (for example: public policy, economic and social context, education systems, etc.) as well as in awareness of SDGs (highlighted in this paper). However, the cross-border mobility that currently exists (for education, employment, trade, etc.) together with the global nature of SDGs and sustainable development challenges unconstrained by geography may account for similarities to some extent.

Given the resonance between priorities in both jurisdictions, this suggests there is scope for education provision to develop these competences in similar ways in both jurisdictions or indeed in more connected ways. Specifically, partnering between universities can enable an exchange of best practice. The design of the Summer School, a joint project between two such universities, was informed by several strands of research including these survey findings: in particular, the top five most important competences (Problem Solving, Communication, Teamwork, Respect for Others and Critical Thinking). The Summer School also specifically addressed Intercultural Skills (ranked as one of the least important competences in this survey).

The impact of survey findings on curriculum design and engineering education in both jurisdictions arises through providing a better understanding of stakeholder perceptions (amongst survey respondents) and also in contributing to the design of a cross-border Summer School. The Summer School seeks to provide a model of best practice in engineering education (offering a concise, focused and innovative approach (including innovative teaching practices) to cover SDG content). Educators could emulate this in other jurisdictions, as they balance requirements to introduce SDG material in an already packed engineering curriculum.

Limitations

This paper presents interesting findings from an exploratory survey which offer a snapshot of perceptions on priorities for skills to address SDG challenges for future engineers. It is important that these are interpreted with a degree of caution given practical and resource constraints associated with the survey; these affect the extent to which the findings may be generalised.

Further Research

Further analysis could examine data on preparedness of graduates and priorities for teaching. Interrogating data by sub-group (gender, category (employer / educator / student), employer size (SME vs large multi-national), etc.) may also help to explain differences and similarities in the two jurisdictions, such as: difference in awareness of SDGs; and whether similarities in importance of competences are consistent in sub-groups.
There is also scope for further potential research to: 1) compare the outcome of the survey in each jurisdiction with local accreditation criteria (defined by Engineers Ireland and Engineering Council UK, respectively); and 2) examine the impact of Brexit on skills from the perspective of mobility of engineers (considering for example: Washington Accord and work being undertaken by the Engineering Council UK in relation to mutual recognition of professional qualifications).

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The experience of women in engineering apprenticeships | A scoping review

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ABSTRACT

This scoping review aims to synthesise the existing literature on the experience of women in engineering and trade apprenticeships, discuss the common themes and highlight areas for future research. Apprenticeships are not only required to address the current skills shortage in the engineering profession which threatens to impede our ability to deliver on our sustainability goals and restrict economic growth they are also a proven pathway for women to enter engineering programmes. Despite growing social and political interest in increasing gender diversity in the workforce,

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data shows that women remain significantly underrepresented in engineering apprenticeship programs.

This review followed the methodological framework put forward by Arksey and O'Malley (2005) and the PRISMA-ScR extension checklist for scoping reviews (Tricco et al. 2018) and examines studies from the SCOPUS, JSTOR and web of science databases between 2012 and 2023. Results were analysed using a General Induction Approach (Thomas 2006) to produce high-order themes and key messages. The findings highlight several challenges faced by women in engineering apprenticeships including limited access to information and opportunities, poor recruitment practices, negative attitudes and beliefs, discrimination, and a lack of role models.

Despite the challenges, this analysis identifies several strategies that support the success of women in engineering apprenticeships notably mentorship, targeted recruitment and supportive policies and practices.

The results of this scoping review revealed that while there are a small number of studies on the experience of women in engineering apprenticeships it is currently limited to work completed in Australia (Simon and Clarke 2016), United States of America (Wagner and Gordon 2013) (Kelly et al. 2015) (Denissen and Saguy 2014), South Africa (English and Le Jeune 2012), and Chile (Sevilla et al. 2023).

1 INTRODUCTION

1.1 Aims

This scoping review aims to provide an overview of the existing literature researching the experience of women in engineering apprenticeships discuss the common themes and identify areas for further research.

1.2 Background

Apprenticeships are necessary to address the current skills shortage which threatens to hinder our ability to deliver on our sustainability goals and restrict economic growth (GOI 2021).

There is growing social and economic pressure to increase the number of skilled trades people in Ireland to support growth in several sectors. In Ireland, The Expert Group on Future Skills Needs has identified a shortage of skilled labour, which, if not provided, will result in constrained activity in the renewable energy sector (GOI 2021). One of the key recommendations of the report is the need to promote and improve the accessibility of apprenticeships to young people (GOI 2021). Ireland's Action Plan for Apprenticeship demonstrates the Government's commitment to promotion of apprenticeship routes in education (DFHERIS 2021). The Action Plan specifically recognises the importance of diversity and inclusion and offers targeted support to encourage women, to participate. Ireland's record in relation to the participation of women in apprenticeship schemes however is poor. In 2016, women made up only 4% of built environment occupations and only 1% of key trade apprenticeships in the sector (GOI 2021). To encourage more women, we first need to ascertain any challenges or barriers they face through this educational path, so we may work towards ameliorating them. This review aims to synthesise the existing literature on women's experiences in apprenticeships to highlight areas for future research.

2 METHODOLOGY

2.1 Framework

This review adopts a rigorous methodology that combines the PRISMA-SCR extension checklist for scoping reviews (Tricco et al. 2018) with the methodological framework proposed by Arksey and O'Malley (2005). By taking a pragmatic approach we aim to comprehensively identify, evaluate, and synthesise the existing literature on the experience of women in engineering apprenticeships.

Arksey and O'Malley identified 6 areas of focus for performing a scoping review:

1) Identifying the research question or topic.
2) Identifying relevant studies using a transparent and systematic approach.
3) Selecting the studies based on inclusion and exclusion criteria.
4) Charting the data using a standardized data extraction tool.
5) Collating, summarizing, and reporting the results.
6) Consulting with stakeholders to ensure that the review is relevant and useful.

The papers identified using the above method will then be analysed using Thomas' General Inductive Approach (2006). The General Inductive approach is a qualitative data analysis method that aims to derive meaningful themes, patterns, and insights from data without the need for preconceived categories. It allows for flexibility and open exploration of the data to generate concepts and theories directly from the empirical material and requires multiple iterations and closing readings of the material to refine the key concepts into overarching themes.

2.2 Inclusion and exclusion criteria

Included in this scoping review is (a) peer-reviewed journal papers (b) published between 2012 and 2023 (c) in English that (d) examines the experience of women in (e) engineering apprenticeships.

(a) To ensure the validity of the findings this review focuses only on peer-reviewed articles from reputable journals, which are subject to a rigorous process of review and evaluation. This helps to ensure that the findings included are reliable and trustworthy.
(b) A 10-year span is commonly used in scoping reviews. While in some cases it may be appropriate to consider all available literature regardless of age it was determined that research on women's experience in engineering apprenticeships is novel enough not to warrant a longer time span. As apprenticeships are currently undergoing a period of rapid change and revision in Ireland (DFHERIS 2021) it is also important to focus on the most recent available data so findings will be relevant and provide insights that are current and of interest to researchers in the field. A 10-year time span is also sufficient to identify trends and changes in the field over time.
(c) For practical reasons such as the researchers being English-speaking and English being the most prevalent language for academic and scientific communication, the decision was made to only include papers that have been published in English. This criterion reduces the workload on the researchers and ensures accessibility and consistency in the review process.
(d) Only papers that explicitly examine the experience of women will be included.
(e) This scoping review will include only papers that examine all apprenticeships related to engineering, construction, and trade, which are collectively referred to as "engineering apprenticeships"

This review excludes papers published before 2012 and those published in languages other than English. Additionally, any apprenticeships that do not fall under the category of 'engineering apprenticeships' and those that are commonly associated with women such as hairdresser or seamstress, are also excluded.

2.3 Search terms

The search terms were chosen by first defining three key areas of interest: Women, engineering apprenticeships and experiences. These were then expanded on with appropriate synonyms and 'wildcards' to include all variations of the words e.g., *'Wom?n' is* used to include both 'woman' and 'women' and 'apprentic*' is used to include 'Apprentice' 'apprentices' and 'apprenticeship' in the results. Initial search terms included "Irish" and 'Ireland." Including these terms resulted in no search results.

The search terms were then mapped to each database's controlled vocabulary using an iterative process to determine which arrangement produced the most relevant results.

The search terms used in each data base are included in Table 1. below.

Table 1. SCOPUS Search terms

Database	Search terms	Search fields
Web of Science	*((wom?n OR female OR gender OR tradeswom?n) AND (engineer*)AND(apprentic* OR trade) AND (experience OR barriers OR opportunities))*	*Abstract*
JSTOR	*(((((wom?n OR female OR gender)) AND ((engineer* AND apprentic*))) AND (Tradeswom?n)) AND ((Experience OR barriers OR opportunities)))*	*All fields*
SCOPUS	*TITLE-ABS-KEY ((wom?n OR female* OR gender* OR tradeswom?n) AND (engineer* AND apprentic* OR trade) AND (experience OR barriers OR opportunities)) AND (LIMIT-TO (DOCTYPE , "ar"))*	*TITLE-ABS-KEY*

After applying the exclusion criteria as described in section 2.2 the results were further reduced through a screening process following the PRISMA workflow (Tricco et al. 2018) illustrated below.

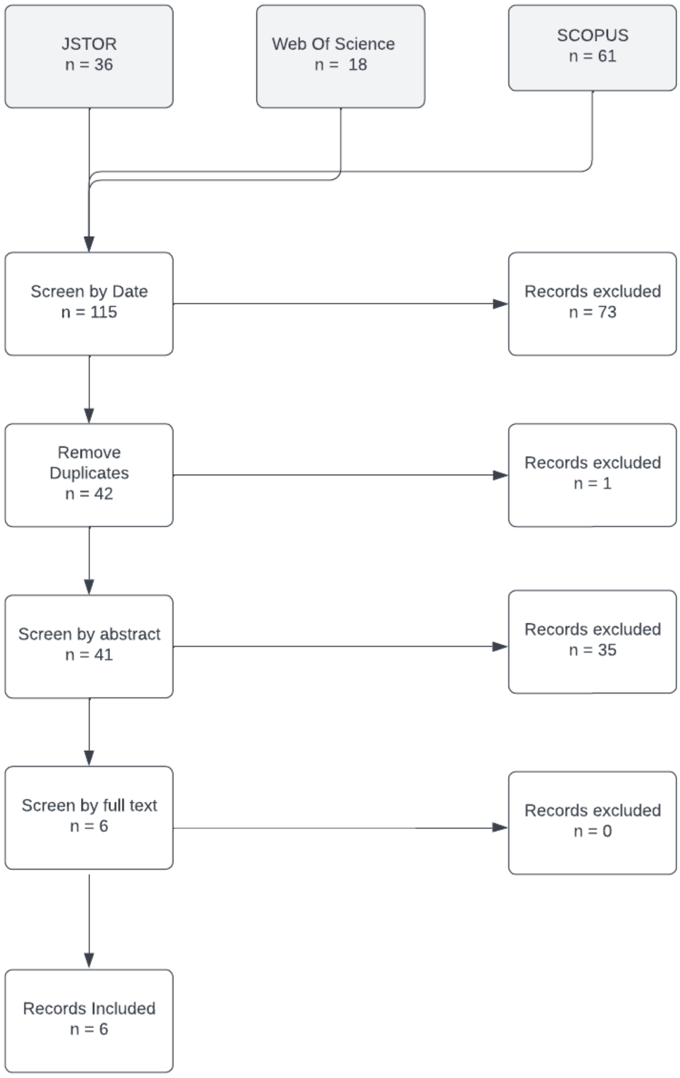

Figure 1. Flow of article search screening process adapted from the PRISMA flowchart

The initial search yielded a total of 115 potential papers. After applying the inclusion and exclusion criteria this was reduced to only 6 relevant papers. Many of the studies in the initial search (n=35) focused exclusively on women's experience within apprenticeships in Higher Education Institutions (HEI's), for example 'STEM research apprenticeships' and as such were excluded from this review.

3 FINDINGS

Using Thomas' General Induction approach for Qualitative Data Analysis 92006), a total of 28 codes were identified that capture the key ideas and concepts presented in the literature. These codes were generated through an iterative process of close reading and careful categorization. The relationships between the codes were then explored to identify overarching themes that encapsulated the main findings across the studies.

By grouping related codes together and comparing their content, higher-order themes emerged, providing a deeper understanding of the challenges faced by women in engineering apprenticeships. These themes include limited access to information and opportunities, poor recruitment practices, negative attitudes and beliefs, discrimination, and a lack of role models. Each theme encompassed multiple codes, for example the following 4 codes are combined into the theme 'Unfavourable beliefs and attitudes'

1. *Poor self-efficacy*
2. *Parents or family expressing negative attitudes towards apprenticeships*
3. *Womens own poor perception of the industry*
4. *Harmful stereotypes pertaining to women's physical capabilities*

Some codes were present in more than one theme for example harmful stereotypes was classified in both 'unfavourable attitudes and beliefs' and in 'discrimination and gender stereotypes' illustrating the complexity and interconnectedness of the issues faced by women in apprenticeships.

3.1 Limited Access to Information and Opportunities

Limited access to information and opportunities stands out as a primary barrier. Young women often lack awareness of available apprenticeship programs, and even when they possess an awareness about apprenticeships, they frequently face obstacles in accessing the necessary information to make informed decisions about their career paths (Simon and Clarke 2016) (English and Le Jeune 2012) (Sevilla et al. 2023). This informational gap begins at school level, where boys typically receive information on apprenticeships as a career choice there is a dearth of information provided to young women students about apprenticeships as a career path. This disparity persists even as women enter apprenticeship programs, where research indicates that they are disproportionately affected by the absence of the informal network that benefits men in the workplace. Consequently, they may receive fewer opportunities and be less likely to be assigned tasks that are critical to their success as apprentices (Kelly et al. 2015)

3.2 Poor Recruitment and Employment Practices

Poor recruitment and employment practices also emerged as a significant barrier for women in male-dominated apprenticeships. It was found that women were subjected to discriminatory hiring practices (Kelly et al. 2015)(Sevilla et al. 2023)(English and Le Jeune 2012), excluded from the formal and informal interpersonal relationships that are essential for apprentices to succeed (Kelly et al. 2015), are disproportionately affected by layoffs (Kelly et al. 2015), often paid less than their male counterparts (English and Le Jeune 2012) and less likely to have a mentor. Furthermore, it was found that women often face a lack of appropriate personal protective equipment (PPE), workwear, and facilities and that this has a negative effect on women's experience in apprenticeships (Wagner and Gordon 2013).

3.3 Unfavourable Attitudes and Beliefs

The research suggests that unfavourable attitudes and belief, both of women towards engineering apprenticeships and of others towards women in male-dominated industries contribute to low uptake and negative experiences of apprenticeships among women (Kelly et al. 2015) (Simon and Clarke 2016) (English and Le Jeune 2012) (Sevilla et al. 2023).

It was found that women often have a negative image of the industry (English and Le Jeune 2012), coupled with the lack of awareness of career opportunities, this can lead to an inadequate number of female applicants, which perpetuates the male-dominated culture of these industries. Simon and Clarke (2016) highlight the importance of the attitudes and beliefs of friends and family towards apprenticeships; Women whose parents have positive attitudes are more likely to enter an apprenticeship.

3.4 Discrimination and Negative Gender Stereotypes

It was noted that women must overcome a high cost imposed by the negative gender stereotypes they encounter when they enter male-dominated apprenticeship programmes (Sevilla et al. 2023). This cost may be emotional or professional, as they may feel unwelcome or excluded from the tasks and informal relationships that are important for apprentices to progress in their training.

These stereotypes are formed and reinforced in schools, where girls are often not encouraged to pursue careers in engineering and construction (Kelly et al. 2015). The review suggests that there is a lack of information and career guidance about careers in these fields which also aligns with the finding of limited access to information and opportunities (3.1).

It is worth noting that two of the included studies adopt an intersectional perspective that examines the experiences of women in relation to their gender intersecting with race and sexual orientation (Kelly et al. 2015) (Denissen and Saguy 2014). Their findings suggest that, in cases where discrimination intersects with race, gender tends to be a more reliable predictor of acceptance compared to race (Kelly et al. 2015).

3.5 Lack of Role Models

A lack of female role models in engineering apprenticeships was identified as a significant barrier for women (Simon and Clarke 2016) (Kelly et al. 2015) (English and Le Jeune 2012) (Sevilla et al. 2023). Women may struggle to envision themselves in these industries without seeing other women who have succeeded in these careers. The very nature of the apprenticeship model of vocational training and employment depends on both formal and informal mentoring partnerships for the success of the apprentices (Kelly et al. 2015) (English and Le Jeune 2012). A lack of female role models puts young women in apprenticeships at a disadvantage when compared to their male counterparts. Exposure to role models was the most frequently mentioned ‘enablers’ when educators, industry and community groups were surveyed by Simpson and Clarke (2016).

4 CONCLUSION

In conclusion, this scoping review finds that women in engineering apprenticeships face significant challenges. The barriers identified include limited access to information and opportunities, unfavourable attitudes and beliefs, negative gender stereotypes, discriminatory practices, and a lack of role models.

The implications of this study highlight the urgent need for addressing the barriers faced by women in engineering apprenticeships and improved dissemination of information to promote and enhance the representation and success of women in apprenticeships which in turn will lead to a more diverse and inclusive engineering workforce.

A comprehensive approach is needed to ameliorate these barriers which includes both ‘top down’ government policies and grassroots initiatives. Targeted outreach programs to schools and encouraging women role models can increase uptake and retention of women apprentices.

It is crucial that recruitment and employment practices are gender inclusive and provide the appropriate PPE and facilities. It is also necessary to address the negative attitudes and beliefs not only within the industry but also at a community and family level to encourage the full participation of women in the workforce and create an environment where women can thrive.

While the Irish Government has made commitments to ensure equity of access to apprenticeships programs so that underrepresented groups are able to avail of apprenticeships (DFHERIS 2021) it is important to note that this scoping review failed to find any research on the experience of women in apprenticeship programs in the Irish context thus identifying a key area for future research.

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ARE ENGINEERING TEACHERS READY TO LEVERAGE THE POWER OF PLAY TO TEACH TRANSVERSAL SKILLS?

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ABSTRACT

What conceptions do teachers hold about learning activities to develop students' transversal skills? This qualitative exploration at a research-intensive engineering school draws on interviews and focus groups to explore teachers' ideas about developing individual transversal skills. We frame our analysis with a model that distinguishes three phases for skill development: conceptual knowledge (knowing), procedural skills (doing) and meta-cognitive/emotional reflection (learning from doing). We are particularly interested in the potential for play to create favorable conditions for developing transversal skills by enabling (i) focused experiential learning, (ii) low-stakes experimentation, (iii) rapid feedback, (iv) opportunity for reflection. In the interviews, the potential to teach conceptual disciplinary knowledge

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dominated teachers' perceptions and transversal skills were sidelined. Focus group participants, just after a hands-on activity, primarily addressed transversal procedural skills in their comments and overlooked the conceptual knowledge underpinning these skills. The importance afforded to meta-cognitive and meta-emotional reflection varied greatly amongst teachers. Our analysis suggests that the three-level model can assist teachers by providing a structure to ensure each level is accounted for in experiential activities. We see promise for addressing transversal skills including sustainability, risk assessment, ethical reasoning and emotional regulation.

1 INTRODUCTION

While there is broad agreement about the importance of integrating transversal skill development in engineering curricula both within higher education and in society at large, that it is a major focus of research communications suggests that it is not trivial. In addition to relying on knowledge outside most teachers' disciplinary expertise, transversal skills are inherently procedural. This means that the process itself is of primary importance, something often overlooked when students' learning is assessed by the final product. Thus, while projects should support the development of students' transversal skills, the format of the feedback and assessment engineering students encounter in projects typically does not favour learning these skills. Another aspect that appears to undermine the development of transversal skills is that students are rarely prompted to reflect on the process. To bring greater visibility to each type of thinking, we identify three aspects for skill development: conceptual knowledge, procedural skill and meta-cognitive/emotional reflection.

This article reports an empirical study at a large, research-intensive Swiss engineering school investigating teachers' conceptions of what students need to learn transversal skills and opportunities afforded by playful approaches. Our objective with this exploration is not to establish the actual benefits or barriers, but rather to understand teachers' conceptions of these issues with a view to providing support that addresses their concerns. In the following section, we present our framework for structuring activities for teaching transversal skills and review the literature using playful approaches in higher education.

1.1 A framework for structuring activities for transversal skill development

Transversal skills involve both knowing (conceptual knowledge) and know-how (procedural skills). Taking the transversal skill of "project planning" as an example, students need to know the names, steps and relative merits of different project planning tools and strategies. Developing students' procedural skill to effectively apply their conceptual knowledge requires them to have opportunities to, for example, select and employ project planning tools. There is no shortage of ways to make conceptual knowledge available to students (books, lectures, videos…) and engineering programmes are increasingly adopting project- and challenge-based approaches that provide students with practical opportunities to use procedural skills. When these experiences incorporate authentic constraints, they offer excellent opportunity to integrate transversal skills with disciplinary thinking. However the number of different things going on in parallel can impede students' capacity to attend to the transversal skills. This lack of visibility is exacerbated when feedback and assessment activities do not explicitly include transversal skills. The result is that students do not acquire skills, such as teamwork, by working in environments where such skills are needed (Picard et al. 2022). Indeed, it has been exhaustively documented that transversal skills must be explicitly taught in order for students to develop these skills (see Lehmann et al. 2008).

A further barrier to developing transversal skills is that the curriculum is often not designed to encourage students to transfer skills developed in one context to other contexts (Tormey and Isaac 2022). Given that equipping students with transversal skills that they can apply in their future projects and across their professional life is a key motivation for teaching these skills, transfer should be a central concern. An important mechanism for enabling transfer is meta-cognitive and meta-emotional reflection, where students think about their thinking or emotions. This meta-thinking enables us to better recognise patterns and has been identified as fundamental professional skills for solving non-routine problems, managing lifelong learning and interpersonal relationships (Shuman et al. 2005). Students typically require explicit prompts to engage in *learning from doing* meta-cognitive and meta-emotional reflection (Steele, 2018).

Our framework (Figure 1) provides teachers with a structure for learning activities targeting transversal skills. The first of the three levels is conceptual knowledge, identified as the factual knowledge and concepts that underpin a skill. Taking ethics as an example, being able to describe the impact of bias in teamwork. Continuing this example, procedural skills level could be leveraging conceptual knowledge to employ strategies for equitable teamwork. Metacognitive and meta-emotional reflection is the third level and refers to self-monitoring activities around the implementation of the conceptual knowledge and procedural skills. One example would be students comparing their experience of one decision-making strategy to what they used the preceding week. Thinking about both the process and the result improves our ability to identify when an approach works well and when to switch strategies. This type of reflection is fundamental to students transferring the skills they learn to their next project.

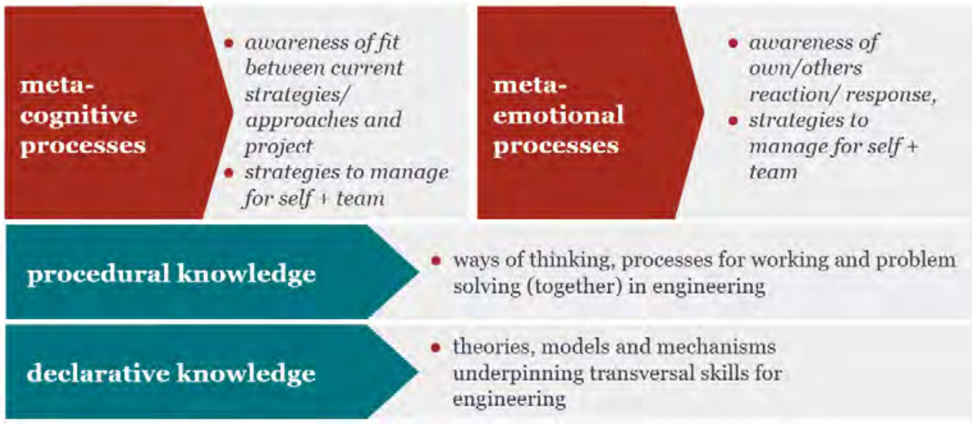

Fig. 1. 3-level approach to l transversal skills

While the development of transversal skills requires students to experience all three types of thinking, our model does not imply temporal order. Indeed, experiential learning may involve students accessing conceptual knowledge only after they realise its relevance. Our framework strives to make the development of a transversal skill more explicit for teachers such that they can ensure that students encounter activities that prompt thinking at each level.

1.2 The case for playful approaches to teaching transversal skills

Play allows us to experiment, to see new things and to try new things - highly useful conditions for learning. Furthermore, play can get us to take on challenging and frustrating experiences while decreasing the potential risks of failure from experimenting. Bodnar et al.'s recent review in engineering education found broad consensus among teachers that games are useful learning tools (2016). While the demarcation is not rigid, numerous scholars have articulated the distinction of formal, rule-based play (which includes games and gamification) from more improvisational and open-ended play such as with LEGO blocks or role playing. Despite the apparent trend towards games in engineering education (Bodnar et al. 2016), we see opportunity to leverage play to create experiential activities focused on transversal skills.

Our interest in the value for play to address a broader set of engineering skills is coherent with Nørgård et al.'s (2017) and Bodnar et al.'s (2016) characterisation that play-based learning supports (i) focused experiential learning, (ii) low-stakes experimentation, (iii) rapid feedback, and (iv) opportunity for reflection. Indeed, the process-driven approach central to play is ideally suited to learning transversal skills. This is a marked contrast from engineering programs' typically product/outcome oriented activities, such as problem sets or building robots, that can obscure the transversal skills. The result is salient for transversal skills currently under addressed in engineering education, such as systems thinking, collaboration, and emotional regulation (Bodnar et al. 2016, Kovacs et al. 2020).

2 STUDY METHODOLOGY

2.1 Data Collection Protocols

To explore teachers' conceptions about teaching transversal skills, we chose the qualitative methodologies of interviews and post-activity focus groups. Guided by the questions in Table 1, we employed a semi-structured approach to investigate participants views and omissions (Kvale and Brinkman, 2009). Approval was obtained from our institutional research ethics committee (038-2022).

Table 1. Interview (1-4) and Focus Group (5-8) Questions

1. What is « play» in Higher Ed in an institution like EPFL?	5. What is one benefit and one disadvantage for student learning using activities like in this workshop?
2. In your view, what are the benefits of play in higher education teaching? Do you see any challenges or potential drawbacks of play?	6. Focusing on students' transversal skill development, could activities like this be useful in your course?
3. Do you use play or playful strategies in your teaching? How would you describe them? Do these activities target specific skills and/or content?	7. In the activity we did, what transversal skills do you think were developed? What actions or moments supported this development?
4. Overall, how would you describe your experiences with play in higher education settings, if any?	8. Is this activity playful to you? Would you describe this type of activity as playful to your students?

Interviews were conducted individually by Author 1 or 2; median time 35 minutes. Roughly half the interviews took place on campus, the others on Zoom. Focus groups were held on campus, sandwiched within workshops demonstrating an activity targeting transversal skill development and the presentation of our 3-level framework. Author 1 and 3 conducted the focus groups, median time 30 minutes. In all cases, participants received the information sheet and consent form in advance.

2.2 Participants

In Fall 2022, we used a purposive approach to identify teachers from diverse disciplines teaching a range of classes (20-400 students). All seven teachers responded positively to our email request to be interviewed and were assigned names (not starting with F) according to their preferred pronouns. Two teachers (Diana and Isabella) reported using playful approaches and two (Joseph and Mario) used gamified approaches in their teaching. In Spring 2023, we organised two workshops to demonstrate a playful experiential activity using tangibles to teach feedback literacy. The activity was immediately followed by a group discussion. 16 of the 19 people who attended agreed to be recorded. Their demographic profiles represent a range of diverse disciplines, teaching experience and institutional roles. Focus group participants received names (starting with F) based on our interpretation of the audio recording.

2.3 Data Analysis

Transcribed audio recordings were imported as text files in Dedoose qualitative analysis software. We proceeded with an inductive approach to analyzing interview data and a deductive approach for the focus groups. Authors 1,2,3 each performed a preliminary reading of 2 transcripts, identifying interesting extracts with thematic coding. A coordination meeting between authors 1,2,3 served to make a more coherent code book which was then applied exhaustively. Authors 1,2,3 each assumed responsibility for certain themes and re-read all the transcripts to ensure that all relevant instances were captured.

3 FINDINGS

3.1 Teachers' conceptions on teaching transversal skills

While our expectation was that teachers would be least aware of the importance of the meta-cognitive/emotional reflection activities, we were struck by how infrequently the conceptual knowledge underpinning transversal skills was mentioned by teachers. Interview participants, who did not experience the activity, focused primarily on the potential for students to learn conceptual disciplinary knowledge through playful approaches. This was very different for focus group participants who largely neglected conceptual knowledge in their comments. Only Felicia (i), Frida and François stated that the hands-on activities either required or were deepened by providing students' with tools, concepts or models to apply. Faye (ii) cautioned that teachers' may not have the foundational conceptual knowledge about the transversal skills, or the procedural skills, to enable them to be comfortable teaching transversal skills. Other participants in the study did not address the importance of conceptual knowledge related to transversal skills before the three-level model was presented to them.

it's a very good complimentary activity to go along with some other self-awareness tools, to have a combined conversation – Felicia (i)

we cannot expect them to teach something that they themselves don't have, and don't know – Faye (ii)

The procedural skills of level 2 were highly visible to the focus group participants who experienced the hands-on activity. These teachers appreciated the opportunities the activity created to ‘see’ where and how transversal skills were relevant. In one group, there was an interesting discussion about if separate activities were preferable to integration into activities already part of a course. The consensus was that it was easy to lose sight of these skills even when they were the sole purpose of the activity. Participants seemed to agree that the best approach was short activities focused on specific transversal skills in a course where they had the context to apply them more widely. The advantages of ‘zooming in’ on specific skills in lower-stakes environments in parallel to a course project, for example, were attractive to teachers.

someone naturally takes the lead in the group. It always happens… I find [this activity] very suitable for my group of students - Frida (iii)

It allowed people to trial, to test, make mistakes. There were less risks for them. That was a good opportunity for them to understand, to be able to learn what works, what doesn't work – Frederic (iv)

I don't know how much, as a student, I would be able to transfer to paying attention to the feedback if I were in another context. – Franz (v)

the activity is disconnected from other things. So the opportunity is there. The fact that it is disconnected is good. – Fabienne (vi)

For some focus group teachers, the high visibility of the procedural activities may have obscured the ‘desirable difficulty’ of having students encounter authentic challenges to allow them to develop appropriate skills. Frida’s comment (vii) below illustrates a recurrent example of this where teachers suggested that the feedback literacy activity we demonstrated could be used to constitute student teams with low potential for friction. Conversely, Frank’s comment (viii) demonstrates understanding that encountering challenges, such as unequal participation or difficult feedback, is desirable because it creates learning opportunities.

[students] can decide, based on the feedback [they] got and the experience [they] got, who to team up with – Frida (vii)

I would have wished to have been pushed a little bit more out of my comfort zone… If you could find a way to make a little bit more of a critical experience, to go deeper into it, to go into the emotions – Frank (viii)

Teachers’ comments about the meta-cognitive/emotional activities were diverse. Some teachers, such as Felix (ix) and Fatima, expressed concern that if students were not actively involved in the activity then they would not learn. They did not appear to understand that when a session includes a metacognition/emotional activity, the authentic experience of having different levels of contribution to the team, feelings of exclusion and acts of inclusion provide rich material to reflect and learn. Other teachers, Felicia (x), Faye (xi) and Frank, did identify the value of reflection activities.

[some students] may be in the group but not really interact. And you may lose, well not lose them, but see that they are not learning from the activity – Felix (ix)

that's something really interesting to discuss afterwards. You know, self-awareness, how we act under time pressure…. People jump right into [the primary task] and that's something to debrief about – Felicia (x)

I realised after only because we had this very quick and easy check… even though we knew that this was a workshop to develop the skills – Faye (xi)

3.2 Teachers' conceptions of benefits and challenges of playful approaches

With one exception, teachers were positive about the value of playful approaches, primarily due to their conception that such activities increase students' motivation for learning but also students' learning itself (Joseph xii, Mario xiii). Two teachers expressed an interest in research evidence about the impact of play in higher education (Isabella, Mary xiv).

it allows them to explore these topics in a more playful way and then also compete. Right? It's fun to be the best... – Joseph (xii)

I think it was my own interest, to really make sure that I can maximize the number of students that I have that can learn something. – Mario (xiii)

any studies related to the impact that it has on learning. I think it's very good for professors to also see this. Because if we think that it will be impactful in our teaching, then we're going to be more likely to implement it. – Mary (xiv)

Experiencing the benefits of play themselves, either as a participant or a facilitator, was cited by interviewed teachers with positive dispositions towards playful activities (Sara xv). Interview participants focused on conceptual disciplinary knowledge.

So at the beginning, yeah, I was skeptical. And then when I saw the result, I was quite enthusiastic. – Sara (xv)

Teachers also expressed some concerns about using more playful approaches in their classes. The concern Mary (xvi) expresses about the effort of creating or adapting activities was mentioned by several teachers. In particular, teachers' belief that an activity should be relevant to students and well integrated in the course led them to conclude that it would require significant effort. Isabella and Joseph, who both use playful strategies in their teaching, mentioned difficulties with assessing what students actually learn. Teachers not using play did not perceive this issue.

We're so freaking busy doing so many things, it's really difficult. [...] But yeah, I would actually love to do that and explore it. – Mary (xvi)

If [students] don't have the impression that it was efficient, then I think you lose your credibility. And you also lose time, and you lose people's time also. - Sara (xvii)

4 DISCUSSION AND CONCLUSION

Engineering programs laud their graduates' future contributions to resolving the environmental crisis, an endeavour that requires students to have the skills to understand and lead complex interdisciplinary approaches (Akins 2005) that incorporate engineering expertise with sustainability, economic policy, and cultural awareness. The current transversal skill level of engineering graduates is not adequate to these lofty ideals (Craps et al. 2017, Torres et al. 2018). Developing students' transversal skills may require teachers to both acquire knowledge and employ teaching strategies beyond those they currently master.

In this article, we present our three level framework for structuring learning activities to develop transversal skills and employ it to examine teachers' conceptions about teaching transversal skills. Applying the model as a lens allowed us to characterise teachers' conceptions about teaching transversal skills. In the interviews, teachers repeatedly pivoted to disciplinary conceptual knowledge even when discussing hands-on activities. In the focus groups, which were preceded by a playful activity, teachers consistently overlooked the conceptual knowledge underpinning the transversal skills and often equated the procedural experience with skill development. This was reflected in the teachers' heterogeneous awareness of the role and value of metacognitive/emotional reflection.

Our observations are coherent with the previous identified conception that experience equals learning, despite prior work establishing that transversal skills must be explicitly taught (Picard et al. 2022, Lehmann et al. 2008). The persistence of this erroneous assumption likely contributes to teachers proposing courses that require transversal skills without providing students with the associated conceptual knowledge or prompts for reflective activities (Steele, 2018) to truly develop their transversal skills.

Needing to provide conceptual knowledge about transversal skills may increase teachers' concerns about dislodging core disciplinary material and the discomfort of teaching skills outside their own expertise. Yet teachers who experience playful strategies report that seeing the impact on learning reinforced their interest in using such strategies themselves. An important limitation of this observation is absence of representativity in this study population. Interview participants were invited and focus group participants chose to attend a workshop about teaching transversal skills. However, the selection bias of participants only emphasizes our finding that experience alone was insufficient for teachers to accord importance to all three levels present in our model. While most teachers expressed a willingness to embed transversal skills in their courses, many expressed the need for support to do so. Our model provides teachers a structure to ensure the three types of learning activity necessary to develop transversal skills are all addressed.

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EMBEDDING COMPETENCIES IN SUSTAINABILITY AND AUTHENTIC LEARNING EXPERIENCES IN FOOD SCIENCE EDUCATION THROUGH A STUDY PROGRAM-DRIVEN APPROACH

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ABSTRACT

The food sector is experiencing a substantial shift towards Industry 4.0 regarding technological solutions to ensure efficient and sustainable food production. To face the required changes and be able to influence and change existing systems, future candidates must have solid capabilities in their respective subject areas as well as generic skills such as critical thinking, reflection, communication, and teamwork skills.

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At NTNU, a program-driven approach for embedding sustainability and authentic learning experiences in the bachelor program of Food Science, technology and sustainability was conducted. Thematic groups of staff members developed learning outcomes and learning- and assessment methods to ensure coherence in the study program. Sustainability learning outcomes are built into all program-specific courses. Case- and laboratory-based learning, problem-based learning, projects, and peer-review assessments have been included systematically, in addition to a mandatory internship period, to create authentic learning experiences and stimulate the development of generic skills. A significant action was establishing a course introducing sustainable food production in the first semester. Data from an external periodic evaluation of the study program, national student surveys, and NTNU's candidate survey demonstrate a well-designed study program with high overall satisfaction among the enrolled students. Compared to other natural and technical science study programs, the program scored higher on most parameters related to contact with working life. Furthermore, the majority of the candidates reported that they had developed sustainability competencies during their studies.

1 INTRODUCTION

1.1 Sustainability competencies and authentic learning experiences

Food production has a significant impact on our planet, and a joint effort in education, research, and innovation is needed to secure a sustainable food system to feed future populations. The food sector is already experiencing a substantial transition regarding technological solutions, digitalisation, and automation to ensure sustainable food production [1]. However, as Hassoun, Prieto [2] pointed out, the food industry is still in the early stage of the green transition. Universities play a crucial role in enabling students to develop key competencies for sustainable development [3]. As these competencies do not automatically develop in traditional classroom settings, continuous efforts must be made to develop innovative pedagogical approaches. Critical thinking, creative problem-solving, communication, and digital understanding are highly valued workplace skills [4]. Students must actively participate in their learning through collaborative and contextual activities to foster such generic skills. Authentic learning is debated, and multiple definitions exist in the literature. Brown, Collins [5] describe authentic learning activities as "the ordinary practices of the culture", that is, the culture in which professionals practice their domain of knowledge and skills. For food scientists, the food industry, laboratories, sales, research institutes, and academia are examples of relevant practices. Learning experiences in these environments can be achieved through internships, temporary work placements, and excursions. However, authentic learning also includes learning activities that connect learning environments in academic classrooms with professional environments beyond academia [6]. Learning activities are then constructed to give students tasks from the "real world", which supports students in translating knowledge to more practical real-life challenges [7-9]. Examples of activities include problem-based learning, case-based learning, project work, and activities stimulating generic skills in broader terms, such as peer- and self-assessment, oral presentations, and teamwork [10]. In the present paper, the term authentic learning experiences are interpreted in its most general sense in which learning is supported by being situated in an environment that aligns learning objectives with real-world tasks, content and context. This interpretation reflects a constructivist view of learning in which students solve real-world problems through collaboration, combining practices and previous experience [10]. Authentic and contextual learning experiences support students' professional identity formation [11], acquiring an appropriate image of their future profession and how they can contribute to influencing and changing the existing food system. The present paper aims to explore and evaluate a program-driven approach to embed sustainability competencies and authentic learning experiences in a Food Science bachelor's program at NTNU.

1.2 Framework

The BSc Food Science, Technology and Sustainability has an annual admission limit of 45 students, accepted based on Higher Education Entrance Qualifications with an additional requirement of subjects in mathematics and science from upper secondary school. Most enrolled students continue directly from upper secondary school without work experience in the food industry. The study program is connected to the Faculty of Natural Sciences and the research group Food Science, focusing on optimal utilisation of raw materials and new resources to produce safe food sustainably. The research group is cooperating closely with the food industry in research projects, making the education foundation base. The study program council includes representatives of staff, students and working life. NTNU has a strategy that all study programs should be of high quality internationally and has developed a quality assurance system for education. According to this framework, every study program undergoes an annual evaluation to ensure that the course portfolio adheres to current regulations and is developed in line with societal needs. A periodical external evaluation should be conducted every five years for the strategic development of the program.

2 METHODOLOGY

2.1 Process of curriculum design

The academic staff of the Food Science research group were engaged in curriculum design through a four-step process led by the study program director (Figure 1). The staff members worked in thematic groups with a mandate to develop learning outcomes, learning activities and assessment methods of the courses within the theme to ensure proper subject strings, including sustainability and authentic learning experiences in the study program. Two stakeholder surveys were conducted to identify a comprehensive title for the revised study program. Relevant stakeholders were identified as academic staff, students, upper secondary school pupils, industry, and alums. The surveys were distributed via social media, and answers from 996 respondents were collected. The revised curriculum was implemented in the period 2018-2020.

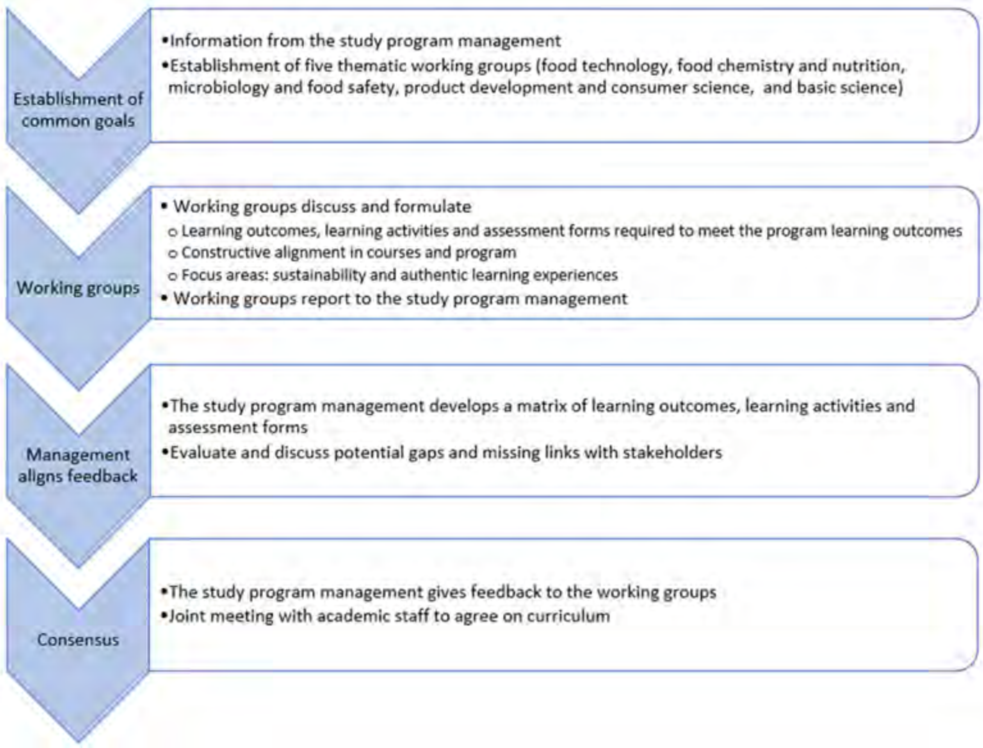

Figure 1. Program-driven curriculum design approach engaging the academic community.

2.2 Data collection for evaluation

A periodical external evaluation of the study program was conducted in 2022 by a committee including two Professors from other Norwegian universities, two industry representatives, two current students and four internal members. A mandate was prepared, and core areas to be evaluated were defined, of which one of these included societal and industrial relevance of the study program and sustainability competencies. Data from NTNU’s candidate survey in 2022 were collected, encompassing candidates that finalised their education between 2019 and 2021. Thirty-four candidates with bachelor's degrees in Food Science, Technology and Sustainability conducted the survey. From NTNU as a whole, the number of responents was 8957. Data from the national student survey “Studiebarometeret” for the Food Science bachelor program and comparable study programs in the time period 2019-2022 were downloaded from www.studiebarometeret.no. The survey is sent to more than 70 000 students in Norway each autumn and includes 40 claims divided into eight subject areas.

3 RESULTS AND DISCUSION

3.1 Curriculum development through a program-driven approach implementing competencies in sustainability and authentic learning experiences

Sustainability learning outcomes (SLO) and authentic learning experiences (ALE) were developed in the majority of the program-specific courses (Table 1). A significant action was establishing the introduction course "Food, Processing Technology and Sustainability" in the first semester. In this course, the students are introduced to the food industry and trained in identifying sustainability challenges in the food value chains. Combining lectures, excursions, guest lectures from the industry, group assignments and practical work, students get an overview of the food sector from the beginning of their studies, and they are trained in system thinking, collaboration, and problem-solving. This introductory course is important for building a collaborative learning culture and clarifying the expectations of being an active student. Another important aspect is SLO integrated as part of the internship assignment, so students achieve knowledge on how companies work with sustainability issues in the short and long terms. SLO is also implemented in traditional courses, e.g. food microbiology. In this course, writing a Blog is used to develop a paper on a chosen topic combining microbiology and sustainability, such as antimicrobial resistance within the food production chain, food spoilage, and the use of microorganisms in bioplastic production. By applying Blogs, students and teachers can discuss and contribute to each other's work during the semester in a peer-assessment process. In the last semester, students write a bachelor's thesis. In 2022-2023, 60 % of the theses were related to sustainable food production. Examples of thesis topics were the processing of seaweed, utilisation rest raw materials of food, novel food products and reduced food waste.

ALE is implemented throughout the curriculum through case-, problem- and project-based learning modules. Furthermore, the study program has a one-semester mandatory internship within the food industry or research. A stepwise and systematic training in peer assessment was developed and implemented in the study program, involving two program-specific courses per study year. Peer assessment is an authentic learning experience, reflecting modern working life by training students to give and receive critical professional feedback. Based on the revised curriculum content, academic community discussions and two surveys (996 respondents) conducted among staff, students, alums, upper secondary school pupils and other stakeholders, the study program name was changed from BSc Food Technology to BSc Food Science, Technology, and Sustainability. Academics responsible for more general courses, e.g. maths and informatics, were not included in the process, as these courses are given to a broader group of students representing a high number of study programs. However, the findings of The Technology Studies of the Future [12] stated that the contextualisation of general courses is also critical and must be implemented. Several barriers exist among students and staff to student active learning methods [13], which must be solved to succeed with a curriculum as described in the present paper. Pedagogically competent staff and leadership are of utmost importance, which stimulates a pedagogical culture of active learning among staff and students. Barriers can also be related to institutional, physical and technological factors, as reviewed by Børte, Nesje [13].

3.2 Evaluation of curriculum

The periodic evaluation committee concluded that the study program is well designed with relevant and well-described learning outcomes and highlighted the employees' strong commitment to development of educational quality and the broad experience with coordinating and leading educational projects. The committee emphasised the strong cooperation between the study program and relevant food actors and industry through cases, specifically through the internship arrangement, where the students are prepared for the working life through contextualisation of previous courses, network building and specific working experience. Although the internship arrangement was acknowledged for its potential as a valuable source of work experience, it was also proposed that students should have the opportunity to engage with different industries enabling them to gain a broader range of experiences and minimise the inherent risks associated with relying on a single business entity for professional development. One measure already implemented to provide students with a broader perspective of the food industry is a mandatory digital interaction between internship students [14], where the students get insight into the work conducted by their fellow students working in other companies. It was further suggested to increase the connection between students and industry through an annual career workshop and to continue and strengthen the already established alum network. This has now been implemented. The committee also highlighted the relevance of the study program design encompassing a large scope of courses and competencies that the industry wants and needs, and they concluded that the students have a solid foundation to build upon when entering the working life, both of knowledge and also competences in laboratory skills, relevant methods, and relevant techniques.

The National student survey during the last four years (Figure 2) demonstrated that students in the study program are generally more satisfied than those in other natural and technical science study programs. The program scored higher on most parameters related to contact with working life than comparable programs. The NTNU's candidate survey shows that almost 60 % of the candidates that graduated between 2019-2021 started to work after the bachelor's degree, while the remaining 40 % continued studying. Approximately 90 % of the candidates who did start working, had a job within six months. This is slightly higher than other candidates at the faculty of Natural Sciences, where 85 % were employed within six months. The large majority of the candidates reported that they had developed sustainability competencies, such as assessing ethical problems (85 %), assessing cases from different sides (86 %), and having the ability to evaluate (85 %) critically (Figure 3).

Table 1. Sustainability learning outcomes and authentic learning experiences embedded in program specific courses of the bachelor program Food Science, Technology and Sustainability at NTNU.

Semester	Program specific course	Credits	Sustainability learning outcomes	Relevance to Sustainable development Goals	Authentic learning experiences	Evaluation §	Relevance to the UNESCO key competencies#
1	Food, Processing Technology and Sustainability	7.5	*Know how preservation method, packaging and logistics are related to sustainable food production *Understand what is meant by sustainable food production and identify how the UN's sustainability goals are linked to food production	1-17	*Laboratory work *Oral presentation *Group assignments	WE	System thinking, collaboration, problem-solving
	General chemistry	7.5			*Case-based laboratory work *Peer-assessment	WE	Collaboration
2	Microbiology and Food Safety	7.5	*Know the role of microorganisms in biogeochemical cycles of nature *Know the most important microorganisms associated with food and waterborne disease, and factors that affect food safety	12,3	*Laboratory work *Oral presentations *Group assignments *Peer-assessment	WE	Collaboration
	Food chemistry I	7.5			*Laboratory work *Group assignments *Peer-assessment	WE	Collaboration
	Statistics and Sensory Methods	7.5			*Laboratory work *Group assignments	WE	Collaboration
	Process Technology	7.5	*Can explain generally about process technology and energy turnover in the food industry *Can evaluate and choose methods that provide the best economic, sustainable and process technology benefit	7	*Written exercises	WE	Critical thinking
3	Food chemistry II	7.5	*Can use knowledge of food processes to make adequate choices for how to process raw materials, produce and store food in the best possible way to minimise food waste	12,3	*Laboratory work *Group assignments *Peer-assessment	WE	Collaboration
	Product Development and Sensory Analysis - Craft Brewing	7.5		8,2	*Product development process in team (including laboratory work) *Oral presentations and discussion	SA-G	Collaboration
4	Internship	30	*Know how a company is working to achieve a sustainable production and how they set their goals regarding sustainability *Apply the company's guidelines for sustainable production and achievement of sustainability goals	12,14	*Oral digital presentations *Peer-assessment *Self-assessment	SA-I	Collaboration, self-awareness, critical thinking, problem-solving

5	Food technology - meat and fish	7.5	*Knowledge of how processing of the raw material and processing conditions can be optimised to lower the environmental impact of the end products	12.3, 8.2, 14.7, 14,4	* Practical and theoretical problem-based learning in team *Peer-assessment *Oral presentation	A (40%), WE (60%)	Systems thinking, collaboration, problem-solving
	Food Technology-dairy and plant food	7.5	* Broad knowledge of product quality, as well as an understanding of how the treatment of the raw material affects the quality of the final product *Knowledge of how treatment of the raw material and processing conditions can be optimised to lower the environmental impact of the end products *Convey attitudes regarding the importance of sustainable production where most possible of the ingredients of the raw materials are used for nutritious human food	12.3, 8.2, 2.4	*Problem based laboratory exercises in team *Group assignments *Peer-assessment	WE	System thinking, collaboration, problem-solving
	Food microbiology	7.5	*Can explain how preservation methods inhibit microorganisms and how food preservation contributes to reduce food waste *Overview of the taxonomy and characteristics of the major microorganisms applied in industrial microbiology, as well as microorganisms that causing quality deterioration or food borne disease	12.3, 3	*Laboratory work *Flipped classroom *Group assignments *Peer-assessment	A (20%), WE (80%)	System thinking, collaboration, critical thinking
	Food Safety and Quality Management	7.5	*Broad knowledge of biological, chemical and physical contaminants in water, raw materials and processed food, and which factors can affect food safety (locally and globally) *Knowledge of hygienic barriers for supply of safe drinking water *Knowledge of environmental management systems (ISO 14001 and EMAS)	12.4, 14.1, 6.1, 6.3, 3	Group assignments: *Outbreak investigation log *Theoretical assignment in food safety *Theoretical assignment in quality management	SA-G	System thinking, collaboration, critical thinking
6	Nutrition	7.5	*Can summarise the main essence of the Norwegian dietary guidelines and recommendations for a more sustainable diet *Can provide simple advice for a sustainable diet	3	*Group assignments	WE	Collaboration
	Bachelor Thesis	15.0	*Knowledge of research and innovation as a promoter for sustainable development in the food sector *Critical reflection about own work and use of sources	12, 14, 3	*Oral presentation of thesis in a seminar *Poster presentation	T, OE	System thinking, collaboration, critical thinking, problem-solving

§WE (written exam), SA-G (semester assignment - in groups), SA-I (semester assignment - individually), A (assignment), T (thesis), OE (oral examination),
#Relevance to the UNESCO key competensies in Education for Sustainable Development

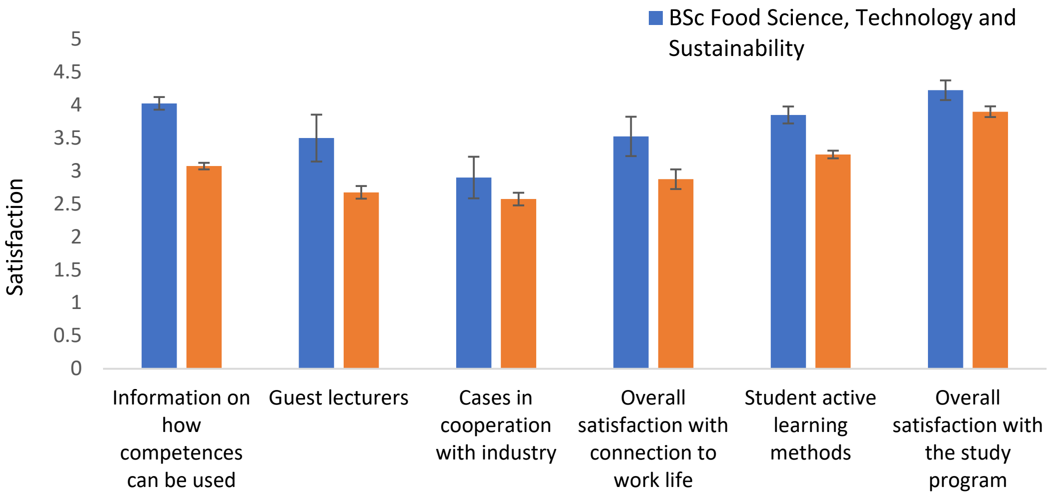

Figure 2 Student evaluation of BSc Food Science, Technology and Sustainability, compared to average evaluation of all study programmes within Natural and Technical Science. Results are presented as average and standard deviations of the years 2019, 2020, 2021 and 2022. Scale (1-5): 1 = Do not agree and 5 = Fully agree

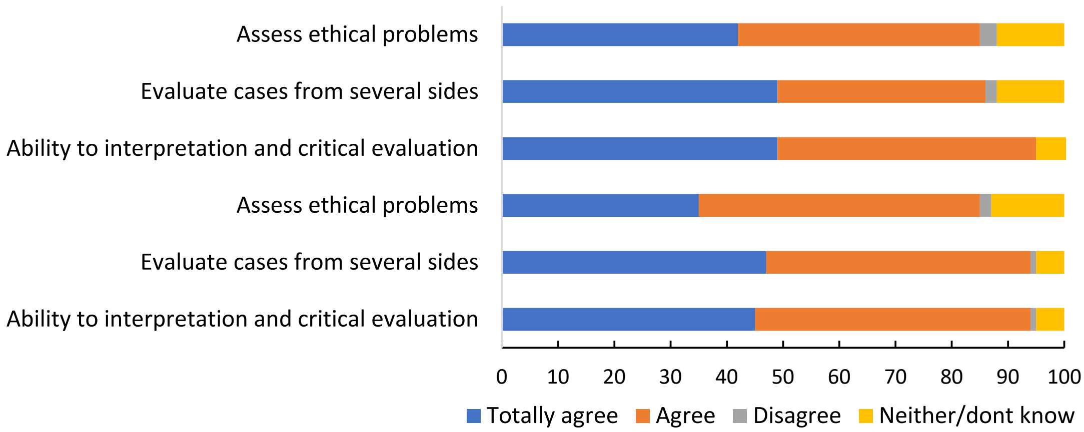

Figure 3 Candidates with a Bachelor of Food Science, Technology and Sustainability degree who graduated between 2019-2021 reported their agreement to claims regarding acquired sustainability skills during education.

4 SUMMARY

Sustainability and authentic learning experiences were successfully integrated through a program-driven process engaging different stakeholders. Curriculum development is a continuous process, and to further strengthen candidates' sustainability competence actions to stimulate interdisciplinarity across the food system educations should probably be emphasised in the coming years.

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NURTURING COMMUNITY: USING COMMUNITY-BASED SERVICE LEARNING IN BIOPHARMACEUTICAL ENGINEERING EDUCATION.

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ABSTRACT
This project evaluates the use of CBSL as a strategy for teaching clinical investigation in the development of biopharmaceutical products based on the nutritional needs of children of a low-income community. To achieve this purpose, our students formulated various functional foods that provided the necessary nutrients for the children in the target community. Afterwards, they drafted the corresponding clinical protocols for each formulation, considering possible ethical implications. The academic evaluation was based on the comparison of courses with and without CBSL. The study found that students showed a slight improvement in academic performance with CBSL. This suggests that CBSL can promote academic excellence while fostering engagement with the local community. Pre- and post-course surveys were used to measure the impact of community work on students and its impact on social commitment. The results showed that students had a greater social commitment to the community after completing the service- based learning activity. This finding suggests that CBSL can play an important role in developing social awareness and responsibility in students. In conclusion, this study supports the use of CBSL as a strategy to promote academic excellence while fostering social engagement and responsibility. CBSL empowers students to make a significant contribution to the local community while also enabling them to learn through practical experience. By incorporating CBSL into the curriculum, students develop a greater sense of social responsibility, which can benefit both their academic and personal lives.

1. INTRODUCTION
Service-learning is a teaching approach that integrates practical experience with academic knowledge by engaging students in community service projects. It has been widely utilized across various disciplines, including medicine, nursing, psychology, and engineering, to enhance learning outcomes and foster civic values, such as ethics and social awareness (Huda et al. 2018).

In the field of biotechnology engineering, experiential learning holds great significance as it allows students to grasp the societal implications of their profession. By addressing biological challenges related to the environment, health, and ethics, students can apply their theoretical knowledge and professional skills in real-world contexts, thereby promoting their intellectual growth (Pierangeli and Lenhart 2018; Vinales 2015; Montgomery 2004).

1.1. Theoretical framework

Community-Based Service Learning (CBSL) is a widely adopted learning strategy in engineering that promotes social values and civic engagement among students. It has been implemented in various engineering disciplines, including biomedical engineering (Baker 2018; Huda et al. 2018; Brown and Bauer 2021).

In biomedical engineering, CBSL involves clinical experiences with community partners. Students work in teams to design devices based on community needs, and with the approval and supervision of teachers and community partners, they test these devices in the community. CBSL has been shown to improve teamwork skills and task distribution in this context (Jaworski and Cho 2023).

CBSL has also been implemented in biotechnology programs in universities. Activities such as tutoring, group problem-solving exercises, discussions on scientific articles, and engagement in community events have been reported. These activities enhance students' professional skills, community participation, and knowledge of practical applications in biotechnology (Montgomery 2004; Hark 2008; Chrispeels et al. 2014; S. 2013).

Service-based learning in the community is crucial for students to gain knowledge, develop social consciousness, and foster critical thinking and civic values. As educators, it is our responsibility to provide comprehensive training that instills social commitment and contributes to creating a better and more equitable society. The goal of this project was to evaluate the impact of service-based learning in reinforcing theoretical knowledge, promoting interest in community work, and applying theoretical knowledge to solve social problems.

2. METHODOLOGY

2.1 General experimental design

This work is a continuation of a multidisciplinary project that began in 2019 at the School of Medicine with students from the Medical Surgeon and Bachelor of Nutrition programs at Tecnologico de Monterrey. The project aimed to involve students from these two programs in community-based service learning (CBSL) through the microbiological and nutritional analysis of a community of children from low-income backgrounds. The goal was to provide nutritional and infectious disease analysis to children and parents and offer solutions to improve their health outcomes.

As part of this effort, two courses from the Biotechnology Engineering program at Tecnologico de Monterrey were involved. The first course was "Food and Bioproducts Development (FBD)," where students evaluated the nutritional and microbiological status of the children in the low-income community. They educated them about the importance of microbiota and proposed functional foods such as probiotics and symbiotics to improve their health. The students worked in teams to develop a functional food that would enhance the nutritional status of the children, considering their anthropometric and microbiological results.

The second course was "Pharmacology of Biopharmaceuticals Development (PBD)." In this course, students analyzed the feasibility of the functional food proposals developed in the FBD course. They drafted clinical trial protocols to evaluate the effectiveness of these functional foods. The protocols were designed to meet Institutional Review Board (IRB) standards and guidelines. Feedback on the drafts was provided by instructors and peers, and the final versions were submitted to the IRB for review. Although the clinical trial was hypothetical and not executed, the purpose was to provide students with the ethical and regulatory context for research involving human subjects.

To evaluate the educational impact of both courses and the CBSL activity, comparisons were made between the final grades, project outcomes, and overall project grades of the group without CBSL activity (year 2019) and the group with CBSL activity (years 2020 and 2021); for the methodology impact in learning process, the students were surveyed with an overall satisfaction survey at the end of each course where not useful (1) to extremely useful (10) scale was used. The students were also surveyed about their commitment to the community to assess the social impact of the project (1 to 10 scale).

2.2 Data analysis

Proportional analysis was used to analyze the ethical and civic components of the project surveys. Numerical data were analyzed using nonparametric Mann-Whitney U tests, as well as parametric Student's T tests, to compare student performance in the two courses with and without the CBSL activity. The data were analyzed using GraphPad Prism (V9, GraphPad Software, USA) and were considered statistically significant with a p-value of less than 0.05.

2.3 Ethical considerations

The study protocol for children's clinical data and sample collection, along with student interaction for evaluation by nutrition and medicine students, and health lessons by biotechnology students was approved by the Institutional Review Board of Hospital La Mision. Preschool director also approved the interaction of our students with kindergarten alumni.

3. RESULTS

3.1. Participants

The intervention involved 54 students, with 19 (35%) enrolled in the FBD course and 35 (65%) in the PBD course. In the FBD course, 63.4% were female and 36.6% were male, with an average age of 22 years. In the PBD course, 56.3% were male and 43.8% were female, with an average age of 23 years.

3.2. Educational impact analysis

3.2.1 Food and Bioproducts Development (FBD)

To assess student performance in the FBD subject, we compared two groups: one without a CBSL intervention in 2019 and one with an educational intervention in 2020 (Figure 1). Despite COVID-19 limitations, both groups showed similar progress in their projects. The group with educational innovation had slightly better final grades, which were statistically significant ($p<0.05$). The overall satisfaction survey indicated that students found the activity relevant to their learning process and its real-life application.

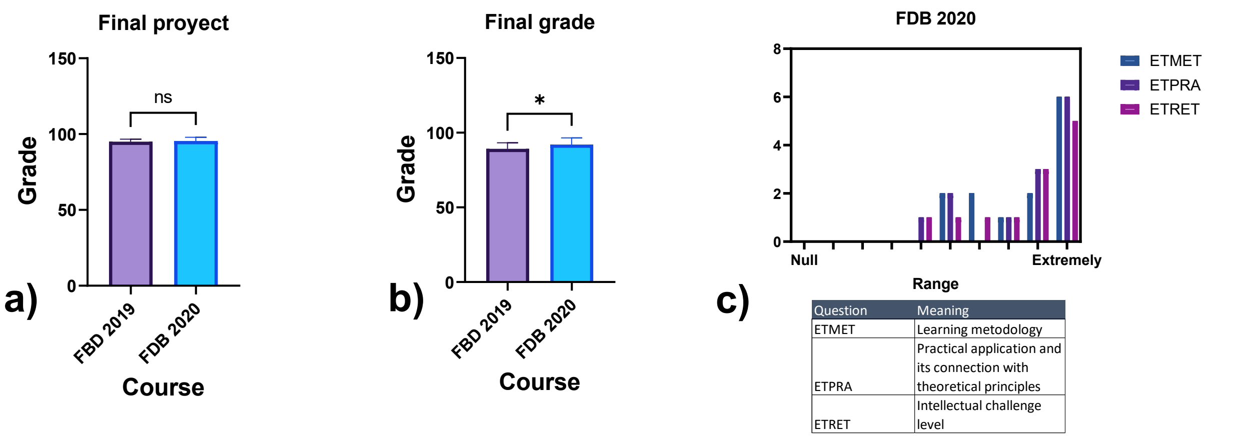
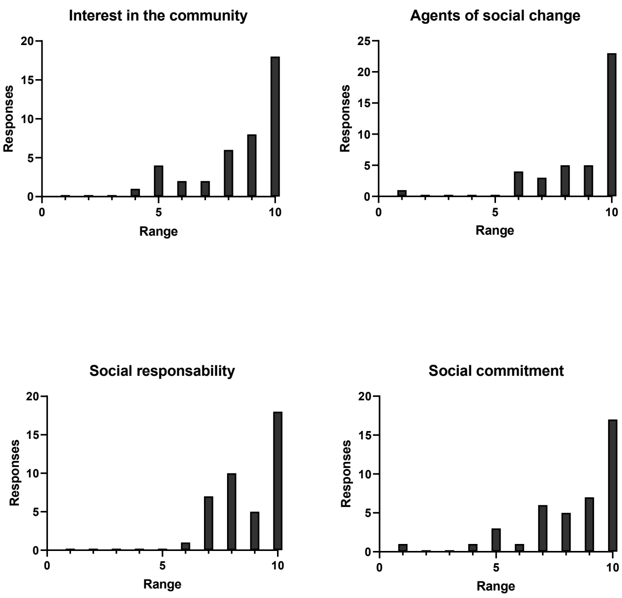


Figure 1. Comparison of ratings of the Food and Bioproducts Development (FBD) groups. The didactic strategy was implemented in the 2020 group of the year, while the 2019 group did not have educational innovation. (a) Grades of the final project. (b) Course final grade. For a), the Mann Whitney U test was used, being not significant. Statistically significant differences (T for Students) for b) are indicated by (*). (c) Post- course students' satisfaction survey show that the students find useful the CBSL methodology in their learning process.

We conducted a survey to assess students' perceptions of service learning, including their commitment to society and sense of responsibility. The questions were rated on a scale of 1 to 10. Here are the results of the survey on their social perception.



Question	Social meaning
I have an interest in other cultures or groups in my community	Interest in the community
I believe that my actions can make a difference in this world	Agents of social change
I am aware of the need to improve the lives of disadvantaged people in my community	Social awareness
I am aware of my social responsibilities	Social responsibility
I feel committed to leading a life of active service to my community	Social commitment

Figure 1. Food and Bioproducts Development (FBD) group social perception. This figure shows how almost half of the students show higher social commitment, social responsibility and consider themselves agents of social change in their community.

Figure 1 shows that most of the students have a strong sense of commitment towards their community and believe that their involvement in activities aimed at community improvement is crucial for promoting social development.

3.2.2. Pharmacology of Biopharmaceutical Developments (PBD)

The subject discussed is an elective course in the Biotechnology Engineering program, offered upon request. It was not available in the August-December 2020 semester due to low enrollment but was offered in 2021. However, due to COVID-19 restrictions, the course had to be adapted, focusing on ethics instead.

During the course, students developed clinical protocols for the community, which underwent ethical review, providing practical training in bioethics within a social context.

To assess learning outcomes, a comparison was made between a control group (PBD2019) without the educational innovation and an innovation group (PBD2021). The parameters evaluated included the final presentation, project, and grades.

The innovation group achieved significantly higher grades in the final presentation (Fig. 3a). In terms of final project grades, there was a decline in the innovation group compared to the control group (Fig. 3b). However, no significant difference was observed in the final grades (Fig. 3c), indicating similar overall performance between the two groups.

Furthermore, a post-course survey was conducted to evaluate the perceived relevance of the activity and its applicability to real-life situations. The survey responses, rated on a scale of 1 to 10, are depicted in Figure 3(d).

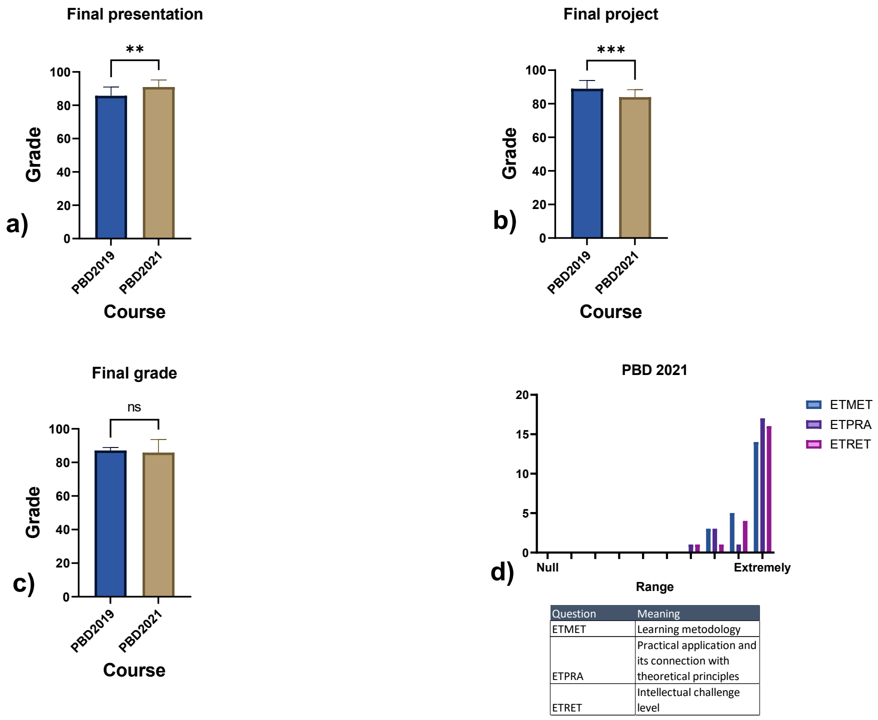
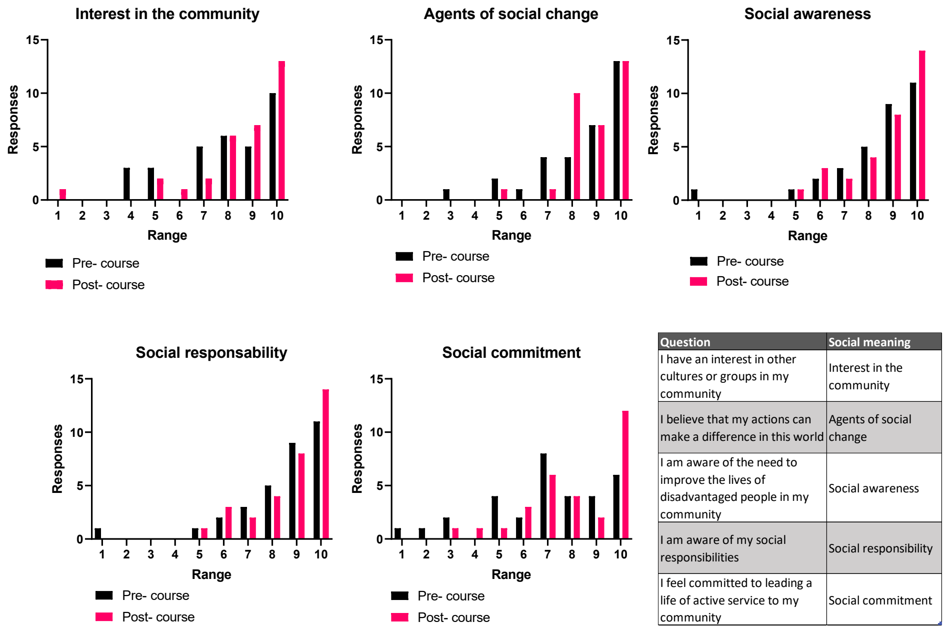


Fig. 2 Comparison of performance of the Pharmacology of Biopharmaceutical Developments (PBD) groups. The CBSL didactic strategy was implemented in the 2021 group, while the 2019 group did not have educational innovation. (a) Qualification of the final presentation. b) Qualification of the final project. c) Final grade. The statistically significant differences (Mann Whitney U) for a) and b) are indicated by (*). For c), the T test of Students was used, being not significant. (d) Post-course students' satisfaction survey show that the students find useful the CBSL methodology in their learning process.

In the PBD group, we compared the results of pre- and post-course surveys that assessed students' perception of service-based learning, including their level of engagement and sense of responsibility towards society. The results of this comparison are presented in Figure 4. We observed an increase in responses close to 10, indicating greater social awareness, after the educational innovation. Specifically, there was an increase in the categories of agents of social change (pre-course 87.5%; post-course 96.90%) and social commitment (pre-course 68.8%; post-course 75.1%). Although there wasn't a significant increase in the other questions, we observed a general trend towards improved social perception among students following the educational innovation. The survey used a scale of 1 to 10 for assessing students' social perception. The results of their social perception are provided below.



Question	Social meaning
I have an interest in other cultures or groups in my community	Interest in the community
I believe that my actions can make a difference in this world	Agents of social change
I am aware of the need to improve the lives of disadvantaged people in my community	Social awareness
I am aware of my social responsibilities	Social responsibility
I feel committed to leading a life of active service to my community	Social commitment

Fig. 3. Pharmacology of Biopharmaceutical Developments (PBD) social perception. This figure shows the impact of service learning on changing students' social perception. In each question we can observe that at the end of the course the students felt greater commitment, responsibility, and interest in community service.

4. CONCLUSIONS

Despite the COVID-19 challenges, the educational innovation had a positive impact on student learning and their community engagement. However, individual differences and the unique characteristics of each group should be considered when interpreting the results. Further experiences with Community-Based Service Learning are needed to better understand the effects of this innovation. Students found the innovation beneficial for their learning and appreciated its real-life relevance. Service learning is seen as a valuable strategy for students to contribute to the community and fulfill their social responsibilities.

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Sustainability and Innovation: Exploring the Relationship between Sustainability and Companies' Engagement in Innovation Ecosystems in German Engineering Industry

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***Conference Key Areas**: Addressing the challenges of Climate Change and Sustainability, Engineering Skills and Competences, Lifelong Learning for a more sustainable world*
***Keywords**: Sustainability, Engineering Industry Survey, Cooperation Formats, Innovation*

ABSTRACT

This study identifies sustainable companies in the engineering industry in Germany and investigates their engagement in innovation ecosystems based on varying collaborative formats and transfer pathways. To this end, 200 medium and large companies were interviewed. For the analysis of the data, the study operationalised sustainability and identified sustainable companies based on responses concerning their environmental, social, and economic performance. These results were then cross-referenced with activities within innovation ecosystems.

Results are consistent with the state of research and indicate that sustainable companies are more engaged in innovation ecosystems than non-sustainable companies. This suggests that companies considered sustainable are more likely to contribute to solving grand societal challenges through innovations. For engineering educators, it highlights the relevance to promote sustainability and innovation as part of engineering education and prepare students for cooperative and collaborative activities in their careers.

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1 INTRODUCTION

The concept of sustainability entered the political discourse with the Brundtland Report in 1987 and took its place alongside the concepts of transformation and innovation (D. Maier et al. 2020; United Nations 1987). At the very latest since the publication of the UN's Sustainable Development Goals, major societal challenges have been viewed through this lens. This is also evident in research on sustainable business models. In the 2010s, there has been an exponential increase in studies on the topics of innovation and sustainability (D. Maier et al. 2020). They point to a correlation between sustainability orientation and innovative strength. In this study, sustainability is understood as economic, ecological and social sustainability following the triple bottom line model (Elkington 1998, 1997). The engagement of companies in innovation ecosystems could be identified in other countries as a factor for innovative strength and thus as an important variable for the emergence of transformative products and services (Kuhl et al. 2016). Innovation ecosystems are a structured set of multilateral partners that interact on the basis of an aligned interest (Adner 2017; Jütting 2020). Interactions rely on various formats of engagement, collaboration, and transfer pathways so that, conversely, the level innovation activity can be inferred from formats used. This is in line with the work of Gibbons et al. (1994) on knowledge production and Carayannis and Campbell (2009) on innovation ecosystems who state that socially robust, knowledge-based solutions for complex societal challenges need to involve multiple stakeholders from different backgrounds. Sustainability is a driver. Therefore, it is important to have a clear understanding of the type of sustainability orientation as well as innovation-oriented activities in industry.

In order to provide an empirical basis for these theoretical considerations, a quantitative interview study was conducted with 200 medium-sized and large companies from engineering industries in Germany. To this end, it investigates the relation between sustainability orientation as well as the level of success in cooperations respectively and innovation ecosystem activity based on the relevance of various literature based, surveyed formats. The main research interest may be summarised as follows:

> *This study surveys what type of sustainability companies from the engineering sector in Germany practice and investigates whether there are differences regarding collaborative formats and transfer channels used depending on the sustainability orientation and success in cooperations.*

Results complement our understanding of sustainability in innovative engineering practice and are relevant for curriculum development in engineering education. Based on the results engineering educators can align their teaching with industry practice with regard to collaboration formats. In this way, engineering education becomes more relevant in terms of deliverables as well es more interesting for learners.

2 METHODOLOGY

This study was designed as a quantitative survey of industry practices. The survey was conducted in the form of structured computer-assisted telephone interviews

(Weitkunat and Crispin 2000). In November and December of 2021, 200 managing directors or heads of R&D departments of medium-sized and large companies from the automotive engineering, electrical engineering, chemical engineering and mechanical engineering sectors were surveyed. These sectors were selected because they are the four largest industries in Germany. It is assumed that the results are thus as generalisable as possible and have greater relevance. In total, the following cases were realised:

Table 1. Sample by Industry Sector and Size of the Company

Industry Sector	**Staff Headcount 50-249**	**Staff Headcount ≥250**
Automotive Engineering	31	16
Chemical Engineering	31	16
Electrical Engineering	34	22
Mechanical Engineering	30	20

In order to assess the sustainability of a company, 9 questions were analysed based on the assessment of interviewees of their own company's activity with regard to the three pillars of sustainability (ecological, social, and economic sustainability). For the purposes of this study, only those companies that indicate no negative effects in all three dimensions and a positive effect in at least one dimension are considered to be sustainable. Satisfaction with collaborations, the achievement of goals in networks and the importance of different activities were surveyed directly. For this study, companies are considered successful if they achieve a mean value of ≥8 on a 10-point interval scale based on satisfaction and goal achievement.

To determine whether and in what way sustainability orientation (based on self-assessment of interviewees) of the companies relates to cooperative engagement and transfer activities used by them, a sustainability index was developed based on items that survey profit orientation, desirable social effects and reductions in the use of resources. This index is based on the triple bottom line approach.

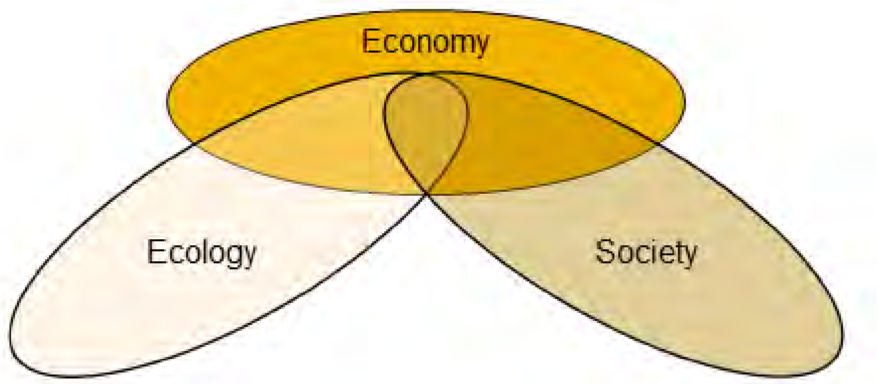

Fig. 1. Triple Bottom Line Approach (Own Presentation Based on Schulz 2012)

The triple bottom line approach is based on the beforementioned Brundtland Report and expands the understanding of sustainability to include the three dimensions of economy, ecology and society. All three dimensions need to be integrated because of their complex interconnectedness (Alhaddi 2015; Elkington 1997). It follows that there is sustainability only if optimisation can be achieved in at least one dimension without deterioration in any of the other dimensions. These conditions may be referred to as pareto-sustainability or pareto-sustainable. Sustainability orientation of companies was operationalised accordingly. Companies are considered sustainable if in their self-assessment they achieve no mean value <3 in any of the three sustainability dimensions, and a mean value of >3 in at least one of the dimensions, with the value 3 being neutral on the scale of the conducted survey ("neither agree nor disagree").

Table 2. Survey Items of Sustainability Index for Classifying the Sustainability Orientation of Companies (Operationalisation in Relation to the Triple Bottom Line based on 5-Point Interval Scale: 1 – 'fully disagree', 2 – 'tend to disagree', 3 – 'neither agree nor disagree', 4 – 'end to agree', 5 – 'fully agree')

Dimension	Item	Mean Value
(a) Economy	(1) Our innovations ensure the economic success of the company (e.g. profit, turnover or market share). (2) Our innovations contribute to overall economic growth and strengthen Germany as a business location. (3) Our innovations are oriented towards a concrete market or customer need.	≥3
(b) Society	(4) Our innovations improve people's living conditions and quality of life. (5) Our innovations have a positive social impact beyond the individual customers. (6) Our innovations are designed with their potential social and societal impact in mind.	≥3
(c) Ecology	(7) Our innovations contribute to climate and environmental protection. (8) Our innovations replace resource-intensive products or processes. (9) Our innovations are created in resource-saving and environmentally friendly manufacturing processes.	≥3

If, to illustrate with an example, a representative of a company answers the three questions (cf. Table 2 items 1-3) of the economic sustainability dimension (with "tend to agree", "neither agree nor disagree" and "tend to disagree", the answers on a 5-point interval scale correspond with the values 4 ("tend to agree"), 3 ("neither agree nor disagree") and 2 ("tend to disagree"). It follows that the mean value for the economic dimension is 3 and, thus, the result neutral (neither economically sustainable nor unsustainable). Assuming identical answers and values for the questions assigned to the social sustainability dimension (cf. Table 2 items 4-6) and thus also a mean value of 3, the classification whether the company in question is considered sustainable or unsustainable depends on the answers to the questions of the ecological dimension (cf. Table 2 items 7-9). If these answers result in a mean value of >3, in the context of this study, the company is classified as sustainable. If, on the other hand, the answers result in a mean value <3, the company is not classified as sustainable but instead considered unsustainable because there is no desirable impact in the respective dimension.

As an additional condition, the sustainability orientation must not be negative in any dimension. If the value in one of the dimensions as depicted in Table 2 is <3, a company is not considered sustainable even if the sum of the mean values of the three dimensions is >9, because it is then assumed that an optimisation in one dimension can only be achieved at the expense of a deterioration in another dimension.

$$S = \{a, b, c \mid a \geq 3, b \geq 3, c \geq 3 \ \land a + b + c > 9\}$$

Sustainable companies (S) are those that achieve a mean value from the associated questions (items 1-3 (a), 4-6 (b), 7-9 (c)) in each of the economic (a), ecological (b), and social (c) dimensions on a 5-point interval scale of greater than or equal to three and whose sum of a, b and c is greater than nine. The operationalisation, then, results in different sustainability categories. Each company is assigned to one category, depending on the focus of its activities. Results are listed in Fig. 2 and Table 3.

A further distinction can be made between companies that indicate a sustainable orientation in only one dimension in which the mean values is >3, companies that consider themselves to be sustainably oriented in two dimensions in which each mean value is >3, and companies that are sustainably oriented in all three dimensions with mean values >3 in a, b, and c. In addition, there are companies that give neutral answers to all three dimensions (mean values for a, b, and c = 3), as well as companies that are classified as non-sustainable because the answers in at least one of the dimensions result in a mean value <3.

In order to investigate a relation between sustainability and innovation ecosystem engagement of the companies, all interviewees were asked about general satisfaction of their cooperation and achievement of set goals. Deviating from the 5-point interval scale used for the other items (1-9 as shown in Table 2), here a 10-point interval scale was used to generate a more precise and meaningful data set. Values 8-10 correspond to "(very) good" satisfaction or achievement of set goals and are considered as successful. All answers in the range 1-7 are clustered and are interpreted as non-successful cooperation in innovation ecosystems.

If questions were answered with "don't know" or "no information", data is not included in the analysis.

Finally, the relevance of formats and activities derived from literature in R&D activities of companies was surveyed. Formats and activities were identified as part of a joint research project with Fraunhofer IAO Center for Responsible Research and Innovation (CeRRI) and Berlin Social Science Center (WZB) (Jütting 2020). For this purpose, sixteen formats and activities were evaluated on a 5-point interval scale. Considered are activities if it ranks "relevant" or "very relevant" for a company, because then it can be assumed that companies use this format at least several times ranging to a regular pursuit of the activity. The data collected allows for a comparison of the respective importance between sustainable and non-sustainable as well as successful and less successful cooperating companies.

3 RESULTS

3.1 Transfer Activities and Collaboration Formats

In order to answer the question of whether and how sustainable companies differ with regard to the transfer activities and collaboration formats they use, first the orientation of companies was operationalised and analysed in regard to the triple bottom line approach (ecological, social, economic). This results in seven possible sustainability profiles, one neutral profile and a non-sustainable profile. The sustainability profiles have an ecological, social or economic focus, or a combination of two sustainability dimensions, or all three respectively. The analysis yields the following results:

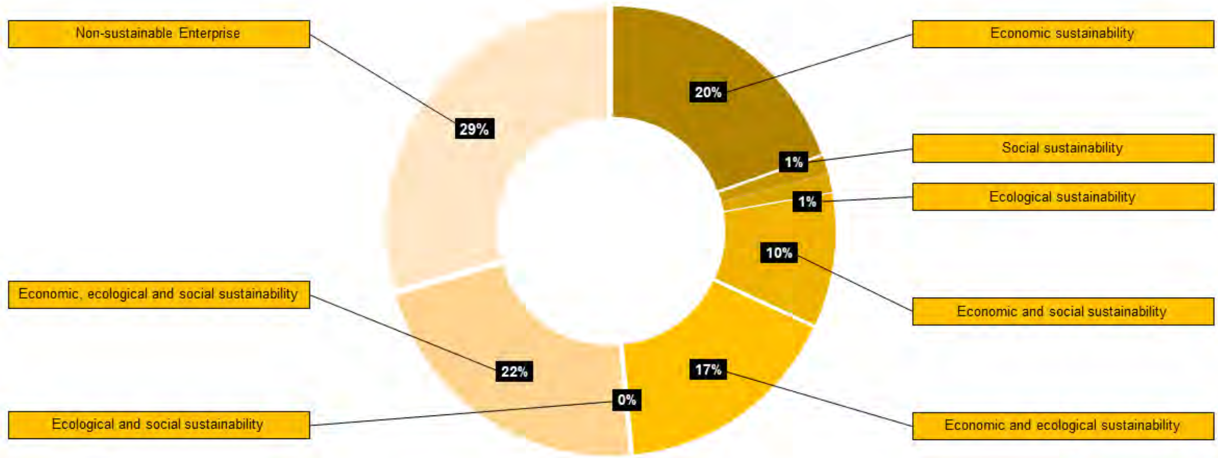

Fig. 2. Sustainability Categories of Companies in the Sample in Percentage

This illustration shows that the majority of companies, namely about 70%, are sustainably oriented. The results thus confirm a shift in mentality among industry. It is striking that only about 20% of the companies have a purely economic sustainability orientation. Conversely, this means that about half of the sample practice social or ecological sustainability. The absolute figures are documented in the following table.

Table 3. *Sustainability Categories of Companies in the Sample in Absolute Numbers*

Category	Number
Economic Sustainability	31
Social Sustainability	1
Ecological Sustainability	1
Economic and Ecological Sustainability	34
Economic and Social Sustainability	21
Ecological and Social Sustainability	0
Economic, Ecological and Social Sustainability	49
Neutral Results	2
No Sustainability	55

For the following analysis, all sustainable companies were subsumed under the category of sustainability. Inconsistent and incomplete data sets were not considered. Thus, 137 companies with a sustainable profile and 57 companies with a non-sustainable profile (including neutral orientations) were considered. Figure 4 shows the percentage of sustainable and non-sustainable companies (on the y-axis) for which the respective activity is either relevant or very relevant in their research and innovation practice (on the x-axis). Non-sustainable companies are cited as a control group to measure whether sustainability orientation has an impact on engagement and activities in innovation ecosystems.

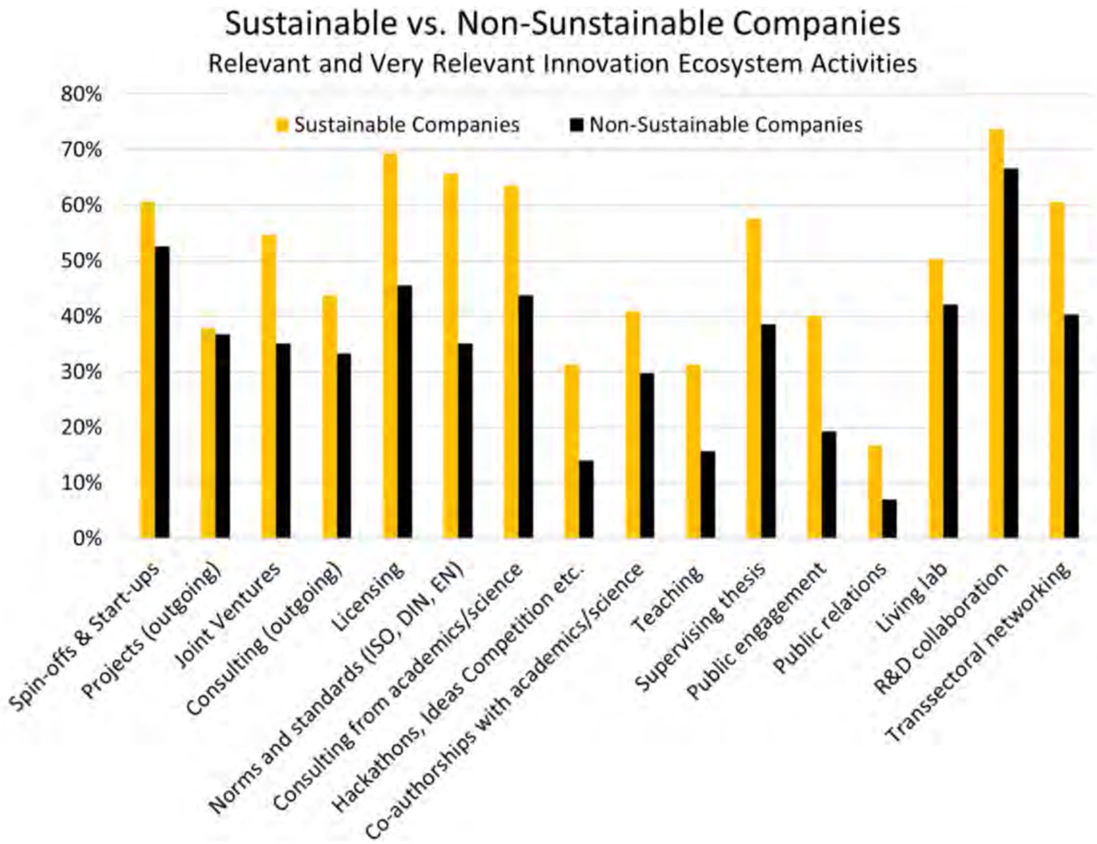

Fig. 3. Activities of Sustainable and Non-Sustainable Companies

Results show that those companies whose interviewees report a sustainable orientation of their organization are more likely to engage in innovation ecosystem engagement and collaborations than non-sustainable companies. Two findings deserve special consideration at this point. First, it may be unexpected that involvement in setting *norms and standards* is significantly more common among sustainable companies, as this is a decidedly traditional activity. However, on closer scrutiny, this alleged incongruity dissipates because sustainable (as well as innovative) companies in particular have a keen interest in normalising and standardising new processes, developments, and products (Thumfart 2022). What is particularly curious, however, and for which it is challenging to find an adequate explanation, is the widespread participation in *living labs* (Parodi and Steglich 2021). At this point, it may merely be pointed out that the format now seems to be established in companies and that from it derives potential for curriculum development in engineering education because it can bring together academic training and practice (Coones, Johannsen, and Philipp 2023). This development is reflected in an ongoing legislative debate introducing a Living Lab Act (Süssenguth and Jagdhuber 2023).

Finally, activities of those companies were analysed that are satisfied with their research and innovation collaborations and report that they are achieving their set goals. These companies were classified *successful* and were then compared with those companies that are less successful in their collaborations. The analysis included 74 companies that collaborate successfully and 113 companies that do not report high success and satisfaction scores. 13 data sets were incomplete.

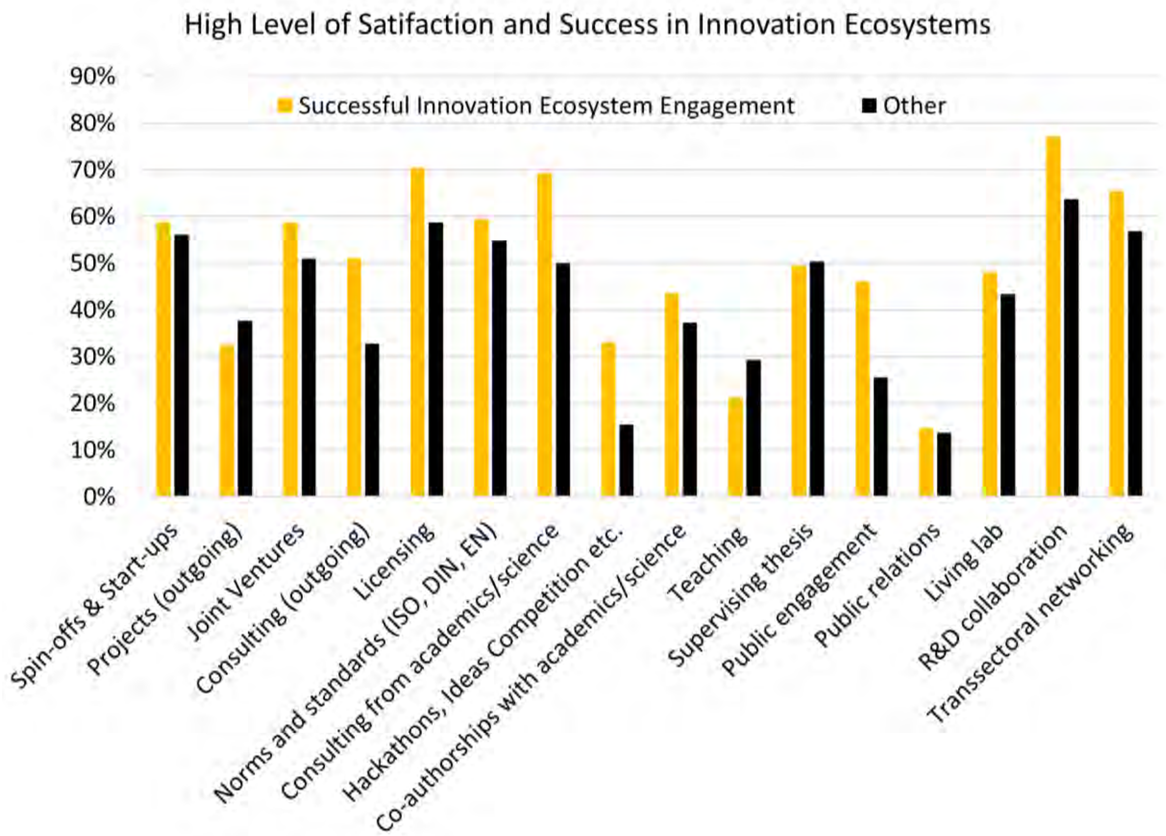

Fig. 4. Activities of Companies with a High Level of Satisfaction and Success in Collaboration

Overall, results show that successful collaborators are more likely to engage in innovation ecosystem activities. However, there is a shift compared to Figure 4 insofar as less successful collaborating companies are more engaged in *teaching* and are more inclined to enter into *joint ventures*. This is also the case for *public relations*, even if the difference is negligibly marginal for the latter.

The fact that collaborative innovation ecosystem activities are widespread is surprising insofar as an even higher prevalence could have been expected based on their relevance in funding policies. Remarkable, however, is that successful collaborative companies use innovative, interdisciplinary, or transdisciplinary formats such as *hackathons* much more frequently and tend to involve the *public* more readily. This practice contributes to a systemic understanding of complex problems and thus helps to find adequate solutions. These results are in line with the state of research in science, technology, and innovations studies as these formats build on the theoretical framework of the quadruple helix which advocates a systematic interaction of the academic, economic, political, and societal spheres (Schütz, Heidingsfelder, and Schraudner 2019). Results of this study may hence be interpreted as empirical support for the approach.

3.2 Limits

The results of the study should be acknowledged considering its limitations. On one hand, only four industry sectors were surveyed. While the comparison of results across sectors suggests generalisability, it cannot demonstrate it conclusively. In addition, sampling errors can occur in random selections (M. Häder and S. Häder 2019). On the other hand, despite the sample size of 200 enterprises, it cannot be ruled out that there is a common method bias (P. M. Podsakoff et al. 2003).

Furthermore, it may be argued that data collection by means of telephone interviews can lead to a reduction in the reliability and validity of the data due to self-reporting of the interviewees (Möhring and Schlütz 2013). It must be considered that answers are (socially) desirable for multiple reasons such as a (subconscious) identification with the employing company. Yet, others argue that self-reporting is limited to assess conscious contents, lacks temporal resolution, and is subject to response sets and memory biases (Pekrun 2020).

3.3 Implications for Engineering Education

Engineering education can benefit from the findings because they highlight the relevance of collaborative activities in professional settings in engineering. With an increasing importance of sustainability and intersectoral approaches to solving complex problems and societal challenges, academic training and higher education also needs to prepare students for these activities. One approach to preparing students for these tasks is to shift the paradigm of curriculum development away from 'first teach the fundamentals' and towards 'start by engaging with the engineering problems' (Hadgraft 2017).

For curriculum development, this means that appropriate formats are integrated into university teaching in the sense of the 'shift from teaching to learning' (Biggs and Tang

2011). The formats, as listed in Fig. 4 and Fig. 5, can be subject to teaching in terms of content or implemented as a proactive teaching format in such a way that students gain experience in the respective formats themselves. However, not all formats are equally suitable. Teaching and learning objectives must remain decisive here. Nonetheless, the list may serve as inspiration for educators.

4 SUMMARY AND ACKNOWLEDGMENTS

The study presented here has shown that about 70% of the companies surveyed in the German engineering sector are sustainably oriented. This is accompanied by an increased engagement in innovation ecosystems of which this study provides an overview. If integrating sustainability into academic training is indeed a declared objective in higher education, then these results provide a strong argument in favour of a more interdisciplinary and transdisciplinary approach in engineering education, in which problem-oriented learning approaches and application-oriented teaching are used to develop transversal competencies that prepare students for the needs of practice, considering sustainable and ethical issues.

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Engineering students emotional intelligence and neuro-linguistics Programming (NLP) as developmental tool

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Keywords: *Emotional intelligence, Emotional intelligence development, Engineering students skills, Neuro-linguistic programming*

ABSTRACT

Emotional intelligence has been increasingly recognized as a critical skill for successful personal, educational, and professional life.

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This article investigates the strengths and weaknesses of engineering students' emotional intelligence (EI) and the possibility of using neurolinguistics programming (NLP) as a developmental tool. Students' emotional intelligence was assessed using the Bar-On Emotional Quotient Inventory (EQ-I) with 5 points Likert scale. First-semester engineering students were approached by part of a broader study at the Budapest University of Technology during 2018-2022. In the article, we describe the emotional intelligence profile of more than 3600 students in various fields of engineering. NLP professionals around the world filled out the second questionnaire. We got answers from 35 professionals based in Tunisia, Hungary, the UK, the USA, and Australia who reported their own experiences using NLP to enhance EI. In this way, we got quantitative and qualitative data. Findings confirm the possibility of using NLP techniques to develop EI and that logical levels, reframing and rapport techniques are best suited to improve engineering students' weaknesses which we determined to be general mood, stress management, empathy, problem-solving, and interpersonal skills.

1 INTRODUCTION

1.1 Engineering Students' skills importance

In the modern world, education is often thought of as primarily focused on academic and technical skills.

However, the importance of human skills in education should be considered. Human skills, also known as soft or interpersonal skills, are becoming increasingly important for success in many industries and professions. These competencies became necessary for the future of engineering students. Having technical skills and knowing how to solve a technical problem is important, but so is having the competencies to be a good communicator and leader (Itani et Srour 2016). The importance of non-technical skills such as communication, teamwork, problem-solving, and adaptability for engineering students has been recognized by the Accreditation Board for Engineering and Technology (ABET) and was added to the criteria in 2001 (Felder 1998). The list of engineering skills, besides technical ones, required for engineering students to pursue their careers is in continuous change. This induces the need for adaptation of competencies to the new technologies' development. In the case of engineering students' skills not matching the job requirements, unemployment may occur. In a comparison study between the skills in demand in 2018 and 2022, it was found that not all the skills required in 2015 would be still needed in 2022 to be able to face the 4th industrial revolution (Kamaruzaman et al. 2019). For example, communication skills, teamwork, management, and leadership skills, other skills were identified as a gap that needs to be addressed. This list includes active learning and learning strategies; creativity, originality, and emotional intelligence (Kamaruzaman et al. 2019).These competencies can enable employees to achieve work results. Learning these skills before facing the employment search phase helps graduates lessen the possible skills gap between what they learned and the industry needs.

1.2 Emotional intelligence importance for engineering students

Studies on the emotional intelligence concept developed in the 1990s by Salovey and Meyer show its increasing importance as a set of skills for the workplace and the educational field.

Employers seek individuals who can effectively manage their emotions and understand their colleagues' emotions, as this leads to better collaboration and a more positive work environment (Masaldzhiyska 2019). Employee productivity is increased by emotional intelligence, which helps the organization meet its objectives on time and with minimal expenses (Anand et al. 2019). According to Goleman and Chernis, it is possible to learn EI within an organization or even individually (Cherniss et Goleman 2001). In their book "the emotionally intelligent workplace," they mentioned the Dreyfus investigation made in 1990 regarding the team-building abilities of scientists and engineers' supervisors and discovered that these abilities were formed during their academic training. This emphasizes the importance of starting to develop EI before finishing formal education.

Higher education institutions are responsible for helping students to gain the proper skills demanded in corporate organizations to ensure the future of emerging engineering graduates (Rugarcia et al. 2000).

1.3 Neurolinguistic Programming as a tool to enhance Emotional Intelligence

Over the past few decades, different techniques have been developed and identified as beneficial in developing emotional intelligence. These techniques include teamwork, self-reflection and empathy-building exercises within emotional intelligence trainings (Nelis, Quoidbach et Mikolajcza 2009; Tucker et al. 2000; Groves, Pat McEnrue et Shen 2008) Through the use of these techniques and interventions, individuals can learn to better understand and manage their own emotions as well as recognize and empathize with the emotions of others.

The Neurolinguistic programming (NLP) approach to developing EI is a new and innovative way to enhance emotional intelligence skills. NLP is a psychological approach that employs various methods and techniques that focus on the connection between the neurological processes of language and behavior, aiming to develop techniques for personal growth and communication improvement. In addition, it can also enhance knowledge, self-management, and mental health while minimizing work stress (Nompo, Pragholapati et Thome 2021).

There needs to be more scientific research on NLP and EI. In search of literature associating the keywords "neurolinguistic programming" and "emotional intelligence" on Google Scholar, we could only find the study of Bin Ahmad, 2019, associating NLP and EI. Bin Ahmed's research focused on providing training to students. He associated 5 NLP techniques for each EI category: self-awareness, self-regulation, self-motivation, empathy, and social skills (Bin Ahmad 2019). The training took him two and a half hours and was administered to 35 students, with another 35 students in a control group.

We found only one article tackling this topic at the study's starting point. A second research published online in 2023 emerged, which we considered for our analysis. The study focused on "The effect of neurolinguistic programming on academic achievement, emotional intelligence, and critical thinking of EFL learners" (Zhang, Davarpanah et Izadpanah 2022). When researching "emotional intelligence" as a keyword in the NLP database, only 2 articles emerged.

The NLP techniques which we used for our research and which are used in the business environment and for the benefit of students are summarized in Table1:

Table 1. NLP techniques cited in the literature

	Objective setting	Rapport	Logical levels	Meta-program	Mirroring
(Joey et Yazdanifard 2015)	x	x		x	x
(Yemm 2006)	x	x	x		
(Kotera et Van Gordon 2019)	x		x	x	
(Singh et Abraham 2008)					x
(Bin Ahmad 2019)	x				
(Javadi, et al. 2014)	x	x			

1.4 Research questions

The lack of research on emotional intelligence and neuro-linguistic programming variables and the importance of EI for students' future in the workplace induced research on NLP techniques used by professionals in the business environment.

The aim of the research is to:

- Determine weaknesses and strengths in the EI of engineering students.
- Determine which techniques would be suitable for the enhancement of the weaknesses of engineering students
- Confirm if the techniques cited in the literature are suitable for coaching techniques for EI improvement, according to other NLP professionals.

2 METHODOLOGY

This research aims to study the degree of emotional intelligence of engineering students and the possibility of using neurolinguistic programming as a developmental tool for their weaknesses. The research is divided into 2 phases. A mixed method approach was used for this study, using descriptive statistics for the first part and qualitative data for the NLP analysis.

2.1 1st research phase: emotional intelligence

The first phase is based on the data gathered anonymized from first-year engineering students between 2018 and 2022. Participants studied at the Budapest University of

Technology and Economics (n=4075-447). They were approached for a broader research purpose with online questionnaires.
In this paper, we focus on their emotional intelligence profile. We used the Emotional Intelligence Inventory test developed by Bar-On (Bar-On 1997a; Bar-On 1997b; Bar-On 2004). The (EQ-I) questionnaire is based on a 5 points Likert scale, and we used the Hungarian version. The inventory contains 121 items, divided into 5 factors, assessed with 15 subscales:

- Intrapersonal scale, which assesses self-awareness and self-expression. Its subscales are self-regard, emotional self-awareness, assertiveness, independence, and self-actualization);
- interpersonal scale, which measures social awareness and interpersonal relationships Its subscales are empathy, social responsibility, and interpersonal relationship);
- Stress management scale, which assesses emotional management and regulation. Its subscales are stress tolerance and impulse control;
- Adaptability scale, which measures change management. Its subscales are reality-testing, flexibility, and problem-solving;
- General mood scale, which measures competencies of self-motivation. Its subscales are optimism and happiness (Bar-On 1997a; Bar-On 1997b).

2.2 2nd research phase: an exploration of NLP practices

The second phase of the research is an explorative qualitative study seeking to confirm NLP techniques that would be most suitable for emotional intelligence enhancement, including stress management.
Existing research on NLP techniques used in the workplace and for EI cites different techniques. Each article represents an individual opinion based on practice and/or literature.
To provide a better view of which techniques would be best used in the work environment in general and in developing EI, we gathered the opinion of several NLP professionals worldwide.
We contacted 20 professionals, training academies, and 1 NLP university sending emails, LinkedIn requests, and Facebook messages on their pages. We asked for their help in sharing the survey with other professionals, and the anonymity of the answers was confirmed. The NLP questionnaire was based on a yes/no answer for most of our questions such as " Are you familiar with the EI (Emotional Intelligence) concept ?" with a matrix representing the question "Please choose the NLP technique(s) that can be used to enhance emotional intelligence (EI) taking in consideration the below definitions" where we provided definitions of different parts of EI and definitions of the NLP techniques.
To avoid misunderstanding or confusing technical terms of neurolinguistic programming, the NLP survey was prepared in 3 languages; French, English, and Hungarian. This is because it might be harder to understand in English for those who learned in French or Hungarian. Timeframe for collecting the answers was starting

November 2022 until February 2023. This research is part of a broader one aiming to study NLP use in the workplace and with EI.

3 RESULTS

3.1 Emotional intelligence of engineering students

Table 2. shows the emotional intelligence profile of engineering students. We converted the results on the scales to percentages to make the comparison more manageable, which means that the scales' ranges are between 1-100. Even more percent a student reach on a scale that higher is his/her named emotional competence.

Table 2. Descriptives of Students' emotional intelligence

Factor	Subscale	n	mean	std. dev.
intrapersonal		4075	60,50	6,334
	assertiveness	4363	58,04	8,211
	self-awareness	4384	57,31	8,721
	self-regard	4421	61,20	9,904
	independence	4407	62,86	13,175
	self-actualization	4399	62,80	11,930
interpersonal		4214	56,19	6,198
	empathy	4441	54,81	9,676
	social responsibility	4382	59,12	7,380
	interpersonal relationship	4358	54,78	7,640
adaptation		4207	57,24	6,882
	reality testing	4379	60,11	8,430
	flexibility	4388	62,15	10,552
	problem-solving	4394	49,56	10,519
stress management		4283	62,39	5,846
	stress tolerance	4396	57,04	7,308
	impulse control	4365	67,75	15,826
mood and motivation		3671	51,13	6,630
	optimism	4369	45,86	10,123
	happiness	4385	56,33	7,290

Table 2. shows that engineering students' strongest skill is impulse control, and they are the weakest in optimism and social-emotional problem-solving skills. They have low-moderate points in interpersonal relationships, empathy, stress tolerance, and happiness.

3.2 NLP techniques for EI enhancement

We asked through a shared survey the opinion of NLP professionals worldwide and gathered 35 answers from professionals practicing in Tunisia, Europe (UK, Estonia, Hungary, Romania, France), the USA, and Australia. 5 observations were removed from the dataset, resulting in a final sample size of 30 answers. The responses provided by those five observations needed to be more consistent or complete, which could have affected the accuracy of results if included in the analysis. 60% of the respondents have more than 5 years of experience using NLP. Three experts had more than 30 years of experience with one of them reporting more than 45 years of experience, which is a great addition to our research knowing that NLP started 48 years ago.

The choice of the techniques to be studied was based on a review of relevant literature. NLP techniques were cited at least twice in different articles as beneficial to enhance emotional intelligence, for students' skills in general, or the business environment.

Table 3. shows the vote of these 30 NLP professionals on the techniques best to be used for emotional intelligence and its factors enhancement. For a better understanding of the results, we made them into percentages. The percentage represents how many experts considered a technique suitable to enhance each emotional intelligence factor.

Table 3. Emotional intelligence and NLP techniques

	Objective-setting	Reframing	Rapport	Logical-levels	Meta-program	Mirroring
Self-awarenesss	60% 18	63.33% 19	53.33% 16	76.66% 23	53.33% 16	43.33% 13
Self-regulations	50% 15	56.66% 17	43.33% 13	60% 18	50% 15	33.33% 10
Empathy	20% 6	46.66% 14	66.66% 20	33.33% 10	43.33% 13	53.33 16
Motivation	73.33% 22	60% 18	13.33% 4	53.33% 16	63.33% 19	13.33% 4
Social-skills	30% 9	50% 15	63.33% 19	56.66% 17	53.33% 16	50% 15
Stress management	36.66% 11	60% 18	13.33% 4	56.66% 17	36.66% 11	20% 6
Emotional Intelligence	46.66% 14	63.33% 18	40% 12	53.33% 16	50% 15	26.66% 8

According to the results in Table 3, there is a variation in the degree of agreement among experts on implementing the researched strategies for improving emotional intelligence and stress management. The findings show that all techniques can enhance the studied skills. According to our experts, the Logical levels technique is best suited for self-awareness (76.66%), and self-regulation (60%). Reframing for stress management (63.33 %). The rapport technique is mainly linked to empathy (66.66%) and social skills (63.33%). 73.33% of the respondents confirmed that motivation could be better enhanced using the well-defined outcome technique. The technique mostly voted as beneficial for emotional intelligence improvement is reframing.

3.3 Analysis

The research aim was to study the strengths and weaknesses of engineering students' emotional intelligence (EI) and the possibility of using neurolinguistics programming (NLP) as a developmental tool. Results showed that NLP techniques cited in the literature are suitable for coaching techniques for EI improvement.

We shared the Bar-On Emotional Quotient Inventory (EQ-I) with first-year engineering students between 2018 and 2022. Results showed they mostly lack general mood skills, including optimism and happiness, problem-solving skills, empathy, stress tolerance, and interpersonal relationship skills. According to our research, their general mood abilities are low-moderate, with low optimism scores and moderately high happiness marks. When it comes to managing emotions, self-regulation can be a valuable tool (Cameron et Nicholls 1998). Our study findings suggest that logical-level neurolinguistic techniques would best help individuals self-regulate for mood management.

Engineering students are also generally expected to have strong cognitive and problem-solving abilities (Kamaruzaman et al. 2019). The outcome of our sample emotional intelligence profile showed that they have low problem-solving skills. Working on improving social skills, in general, helps improve problem-solving skills (Dereli 2009). Our study suggests rapport from the studied NLP techniques is the most beneficial to enhance social skills.

Empathy is an essential skill for professionals in most fields, it is crucial to provide students with appropriate resources and opportunities to develop their empathy skills, especially because, in our research, students scored low to moderate on this skill. Experts in NLP voted mainly for the rapport technique and developing empathy skills.

Stress tolerance could be increased with stress-management skills, for which using the reframing NLP technique is believed to be a practical approach.

Interpersonal relations play a crucial role in our personal and professional lives. Self-awareness skills have been identified as a critical factor in improving interpersonal relations According to our findings, logical levels technique would be beneficial to increase self-awareness and, thus, interpersonal relations skills of engineering students.

4 SUMMARY

Educational institutions aim to provide learners with the knowledge, skills, and values required for their future development. Educational institutions aim to shape individuals who can contribute positively to society and meet the workforce's needs. Emotional intelligence, critical thinking, and creativity are some of the skills that these institutions strive to develop in their students. To do so, determining the weaknesses and strengths of engineering students' skills is crucial. Data gathered from first-year engineering students between 2018 and 2022 showed that their highest strengths were impulse control, while their areas of weakness were general mood which includes optimism and happiness, problem-solving skills, interpersonal relationships, empathy, and stress tolerance.

Our research confirmed that neurolinguistic programming tools can be used to enhance their EI. It also confirmed the possibility of using reframing, objective setting, rapport, logical-levels, meta-programming, and mirroring techniques to enhance students' emotional intelligence. In addition, the most efficient methods to improve emotional intelligence weaknesses points determined in this study are logical levels for self regulation development, and self awareness for their general mood skill, and interpersonal relationship skills. Reframing for stress management. The rapport technique is recommended mostly for empathy and social skills for students empathy and problem-solving skills.

While 30 professional answers may be too few to obtain true representativeness of the entire population being studied, the diverse range of experts who answered the survey with different years of experience means that the data collected should be sufficiently generalizable. Additional responses on the questionnaire are needed to provide a more profound statistical significance.

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TEAMWORK SKILLS DEVELOPMENT IN ENGINEERING EDUCATION: A HOLISTIC APPROACH

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ABSTRACT

Engineering is a profession grounded in teamwork with the need for engineering students and professionals to possess the ability to integrate their work efforts seamlessly and effectively towards a common goal. This in turn necessitates the need for a **comprehensive, tailored, and relevant overarching conceptual framework** to be constructed to ensure that our subsequent generations of engineers are equipped to efficiently tackle existential societal problems including anthropogenic climate change and the multi-faceted nature of sustainable development.

This paper motivates, details, and presents a conceptual framework for implementing successful engineering teams in tertiary engineering projects. The emergent conceptual framework presented is currently a work in progress based on the findings and recommendations of current literature. We plan to undertake student interviews with both first year and capstone students to refine our framework thereby ensuring the credibility of the framework.

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The final theoretical framework is composed of four key themes, these being team composition, team dynamics, creative leadership and team culture. The theoretical composition and relevance of their component sub-themes are discussed further in our work in addition to the unique interplay that occurs at the nexus of said themes and sub-themes. Ultimately this paper does not only define and outline a holistic conceptual framework to be used as a heuristic device for implementing successful engineering teams, but it additionally highlights current gaps in the relevant literature thereby provoking critical fields of future research.

1 INTRODUCTION

The 21st century, while still very much in its adolescence, has produced world shaping technologies that in combination with rapid globalisation have created fertile ground for complex and daunting engineering challenges. Such challenges include existential threats such as anthropogenic climate change which has irreversibly altered the complexion of modern engineering problems. Addressing these challenges requires successful collaboration among engineers, government regulators, entrepreneurs, and industry professionals. The effectiveness of this collaboration is vital to address increasingly complex challenges related to sustainable product development, innovation opportunities, and the progress of our society. Contemporary engineering graduates therefore must be equipped with drastically different skill sets from their predecessors including skills such as communication, leadership, creativity and capability to work in teams (Lappalainen 2009; Farr and Brazil 2009; Muñoz-La Rivera et al. 2020). This has necessitated research into the overarching theme of teamwork skills development and the need for students to be explicitly taught teamwork skills in a pragmatic and proactive fashion (Lingard and Barkataki 2011).

2 BACKGROUND AND MOTIVATION

There are prominent instances of tertiary engineering teamwork being used as a focus for the creation of conceptual frameworks. Such examples often investigate what constitutes effective or successful teamwork through the analysis of student attributes by drawing upon the current body of literature (Chowdhury and Murzi 2019). Further proposed conceptual frameworks are deeply pedagogically focused with highly specific applications (Zamora-Polo et al. 2019) or focused more so on the necessary and desired professional skills that our future engineers must possess in order to tackle new kinds of engineering problems (Kamaruzaman et al. 2019) including how to approach interdisciplinary engineering education (Van den Beemt et al. 2020). There is, however, a distinct lack of conceptual frameworks that incorporate all tertiary engineering education settings as well as encompassing both pedagogical and student-centred factors.

A significant focus of this research paper will be to develop a framework for effective team collaboration based on recent findings from team science research. With an estimated $1.5 trillion invested worldwide in sustainable development research, and an estimated $664 billion in the United States alone (OECD Data), establishing evidence for effective team science practices and policies is sorely needed (Hall et al. 2018). This includes addressing key features that research has identified as potential challenges: the diversity of the team's members; deep knowledge integration; team size; goal misalignment; permeable boundaries; geographic dispersion and high task interdependence (Cooke 2015). To address potential challenges, identified risks, and uncertainty associated with developing plastic-free paper-based point of care diagnostics, our project will be guided by principles of convergence science.

The proposed conceptual meta-framework therefore seeks to not only describe the state of contemporary research in the area of tertiary engineering teamwork education but also link this to pedagogical factors and strategies in order to provide a representation of not only what factors contribute to successful teamwork but also how this is achieved and what strategies educators have employed to achieve this. The construction of a holistic approach to detailing teamwork skills development in engineering education, therefore, motivates the following research question:

What individual, team based and pedagogical factors influence teamwork skills development in tertiary engineering teams and what is the interplay between them?

A conceptual meta-framework is an interconnected set of ideas about how a particular phenomenon functions or is related to its parts based on the synthesis of literature (Svinicki 2010). This conceptual meta-framework strives to elucidate our interpretation of teamwork within undergraduate engineering teams based on current, relevant literature. By qualitatively synthesising pertinent literature in the field and putting forth a framework composed of identified factors as well as the relationship between them we propose a heuristic for educators focusing on elements of teamwork that need to be considered in teaching and improving teamwork skills development.

3 METHODOLOGY AND METHODS

A scoping literature review approach was employed to understand, conceptualise and refine the individual, team based and pedagogical factors that have been seen to influence teamwork skills development as well as identifying potential research gaps (Boelt, Kolmos, and Holgaard 2022; Booth, Sutton, and Papaioannou 2016). This scoping literature review only included peer-reviewed journal articles and conference papers to ensure the manageability and rigor of included data. Further research outputs were gathered through citation searches of highly relevant sources to supplement the existing data corpus (Boelt, Kolmos, and Holgaard 2022).

Consequently, a qualitative content analysis design framework (Borrego, Foster, and Froyd 2014) was deemed to be the most appropriate due to the necessity of capturing meaning within and across literature as opposed to generating new theory through the construction of concepts and conceptual categories (Morelock 2017). A socio-constructivist paradigm was employed (Brown and Campione, 1994) whereby it is a team or group of learners who construct their own meaning and learnings which are dependent on what they experience to be true as a collective (Svinicki 2010). The conceptual framework presented in this work is a work in progress and therefore does not address validation of the framework nor teamwork assessment.

4 RESULTS AND DISCUSSION

Findings from our scoping literature review uncovered numerous pertinent factors that have been linked to the development of teamwork skills within cohorts of tertiary engineering students. Further analysis has since shown the emergence of four prominent categories of influencing factors with these being team composition, team dynamics, creative leadership and team climate. These categories will be elaborated upon further in the following discussion along with their component sub-factors.

4.1 TEAM COMPOSITION

Team composition is one of the most widely studied factors within the field of teamwork skills development with diversity, personality type, and team size being considered pivotal.

Gender and its implications in engineering, a famously male dominated field (Mubarak and Khan 2022), has been studied extensively with important findings related to the effectiveness of engineering teams being elucidated. Female students in engineering teams have been seen to not only exhibit less relationship variance (Zhou et al. 2019) but also provide higher peer ratings (Pasha-Zaidi et al. 2015) whilst receiving lower ratings themselves (Fajarillo, Moussa, and Li 2021). This disconnect between high teamwork skills and low peer feedback scores is symptomatic of a dominant male culture within engineering whereby underrepresented demographics such as women, particularly women of colour, experience great social pain related to being ignored, being the only one, being spotlighted and stereotyped amongst other factors (Ong, Jaumot-Pascual, and Ko 2020). Ultimately this is of great concern as the academic performance and persistence of women within engineering is held back by the overt discrimination that they face and is therefore a pivotal factor that needs to be considered when forming engineering teams.

Diversity of student grades, skills and ethnicity have similarly been identified as factors to consider when forming teams. **Academically diverse** teams have been associated with mixed results, showing no correlation to team enjoyment or effectiveness (Mostafapour and Hurst 2020), frustration from high achieving students (Michalaka & Golub, 2016) and a correlation to visible leadership (Marshall et al. 2016) as well as team effectiveness, positive peer feedback and course outcomes (Zhang et al. 2014; Vasquez et al. 2020). When it comes to the ethnic diversity, educators are encouraged to be mindful that team-based learning alone does not ameliorate the perceptions of low performance and poor decision-making skills that are harboured by students of minority ethnicities (Beneroso and Erans 2020). Although explicit instruction regarding team effectiveness and diversity has been shown to increase students' awareness of diversity, they also become less prone to support diverse and minority individuals (Kirn et al. 2018). This is supported by the work of Jimenez-Useche, Ohland, and Hoffmann (2015) where differences in culture were the leading cause of low team cohesion, satisfaction and high levels of conflict. As future engineers are required to work in diverse workplaces with people of various ethnicities and skill levels these issues must be overcome and tertiary educators must temper the frustration that arises from vast skill disparities as well as nurture all students to support and avoid conflict with students of minority ethnicities.

Personality types have been used as a theoretical vehicle through which effective engineering teams can be formed and as a result there is a plethora of research focused on detailing these phenomena. Many of these works contend that an engineering team will be more successful and integrate work efforts in a more seamless manner if there exists a large variety of personalities within the team. Carl Jung and Isabel Briggs Mysers' personality test (MBTI) has been applied in a plethora of settings with results linking a greater distance between parametric test results to higher creativity, self-reported team capabilities and overall team achievement (DuPont and Hoyle 2015). Self-awareness of one's own MBTI can also lead students to recognise their particular strengths and weaknesses and improve their contributions to the team (Pieterse, Stuurman, and van Eekelen 2021). Similar personality-based tests such as the Enneagram test (Type Descriptions — The Enneagram Institute 2014) have highlighted students' improved ability to learn organisational skills, build relationships, resolve conflicts and emphasise higher standards (Havenga and Du Toit 2019). This sentiment is somewhat echoed by other studies where students have shown their willingness to work together and turn the discomfort of working with others into an opportunity when they are aware that there is a method behind the formation of teams (Michalaka and Golub 2016). Conversely, numerous other inquiries have shown no significant differences between MBTI diverse and randomly allocated teams (Michalaka and Golub 2016) which also holds true for the 'big five' personality traits with the exception of the adventurous trait which is negatively correlated with teamwork competencies (Tang 2020). Ultimately these contrasting findings make it difficult to identify the 'perfect' mix of personalities or whether such a phenomenon even exists. As a result, educators need to use these tools in different ways and apply them to their specific contexts whilst ensuring that their processes are as transparent as possible to ensure the perceived fairness of these teams and elicit student self-awareness.

Team size can be easily overlooked and arbitrarily set, there exists however lessons which can be garnered from the current body of research. Despite some research showing no particular correlation between team size and team effectiveness (Iacob and Faily 2020), large teams of over six members often cause an issue for both students and educators alike as both groups are not able to intervene, communicate and develop capabilities as effectively (Kearney, Damron, and Sohoni 2015). Team members often feel that such large groups stunt their ability to communicate effectively and make decisions which may be countered by the construction of component sub-teams according to expertise and interest (Murzi et al. 2020). Whilst there is no 'one size fits all' solution here, educators should be wary of forming large teams and in such cases consider forming smaller sub-teams within them.

4.2 TEAM DYNAMICS

Team composition is not however the be all and end all of effective team functioning. Healthy team dynamics are crucial in ensuring the ongoing functioning of a team which centres around communication, conflict, psychological safety, team cohesion and motivation.

Whilst **communication** may not be considered to be as important as technical contribution amongst students (Robal 2018), it is a challenge for engineering students (Senna Fouché and Müller 2021) and a skill that is sought after by industry (McHenry and Krishnan 2023). Consequently, the perils of poor communication have been outlined with findings highlighting the consequent lack of feedback, progression towards deliverables, contribution from peers and poorer work quality (Lucietto et al. 2017; Eggert et al. 2014; Petkovic et al. 2014). Regular team communication therefore is key to project success (Presler-Marshall, Heckman, and Stolee 2022) and something that along with individual motivation impacts less satisfied teams proportionally more (Dzvonyar et al. 2018) thereby creating a negative feedback loop where poor communication, **motivation** and low team satisfaction perpetually increase the magnitude of the others. To break this loop, educators must consider the inclusion of explicit pedagogical techniques that relate to mature communication, a method of communication in which ideas are put forth, justified and feedback is provided constructively (Murzi et al. 2020). Additionally, the poor motivation of students must simultaneously be targeted as the antecedent of poor communication (Pertegal-Felices et al. 2019) through various emerging pedagogies tailored to increasing student motivation including point-concept-review (CPR) pedagogies (Lee et al. 2022).

Despite the logical connection between **team conflict** and poor team effectiveness (Mostafapour and Hurst 2020), it is the manifestations of how this occurs that are crucial to understanding conflict. Personal tensions over unequal work distribution (Lucietto et al. 2017) as well as more overt disagreements within a team (Eggert et al. 2014) can stifle the learning and teaching opportunities of other students. The work of Mostafapour and Hurst (2020) further outlines the root causes of such conflict including differences in expectations, lack of communication, poor quality or lack of effort and internal disagreements. Much of this stems from a lack of **constructive controversy** or the process of working towards an agreement when one initially holds an incompatible opinion or ideological position to their counterpart (Johnson, Johnson, and Smith 2000). Constructive controversy should be seen as a growth opportunity for students where conflict is acknowledged and used to fuel progress, something which can be taught to engineering students (Abbasi, Wolfand, and Vijlee 2022).

Psychological safety arises in environments where team members collectively believe that risk taking is a safe practice (Edmondson 1999) and is a concept that lends itself to the study of teamwork in engineering. The lack of psychological safety has been seen to be a persistent issue within the field whereby students feel insecure and as though they are not heard within their teams (Lescott 2022).

Psychological safety is a key pillar in the construction of creative learning environments for engineering students (Zhou 2012) as well as overcoming barriers to students' creativity. Consequently, psychological safety presents itself as a prosperous avenue for future research whereby the forming of psychologically safe environments should be prioritised to ensure team dynamics promote mutual trust and respect (Murzi et al. 2020).

Engineering students value building rapport with their fellow team members and getting to know one another (Thompson 2017) which is inextricably linked to the construction of a supportive, welcoming and successful team environment (Abreu and Read-Daily 2020). This is frequently referred to as **team cohesion** which can be seen as the agglomeration of personality, conflict and communication within teams, acting as the intermediary between team rules and team performance (Avila, Van Petegem, and Libotton 2021). Whilst the importance of both conflict and communication are outlined above, team cohesion in this application refers to the importance of interpersonal relationships built between team members necessitating social networks and trust. Such personal relationships within engineering teams are crucial (Zaugg and Davies 2013) and pedagogical approaches to foster this should ensure the consistency of team membership (Luna and Izu 2023; Vasquez et al. 2020) without neglecting to consider fostering effective communication and conflict management skills.

4.3 CREATIVE LEADERSHIP

In the context of engineering, it is important that leaders understand how to facilitate both idea generation and implementation particularly in design projects. Consequently, leadership within tertiary engineering settings must be considered in terms of student leadership style as well as educator or project manager influence.

Leadership styles are extensively studied in fields such as management, however their application to engineering education particularly in the context of teamwork can yield important results. **Integrative leadership** and conflict management styles involve the consideration of all parties with a view to finding a truly 'win-win' solution for the team (Individual and Team Performance Lab Department of Psychology 2016) and have been correlated with overall team satisfaction (Maliashova, Sultanova, and Sanger 2022). The key to integrative leadership is being able to adapt and compromise without dominating or avoiding team discourse. Leadership within engineering teams is often prescribed however many students do not see the value in effective leadership and only employ suggested leadership structures when absolutely necessary or when approaching deadlines require the effective functioning of a team (Murzi et al. 2020). Ultimately this necessitates the early and effective implementation of pedagogical strategies in team-based units to instil within students the importance of and direct the practice of integrative leadership.

Project managers, mentors, teaching associates and faculty members have been employed across a variety of team based applications with generally excellent feedback highlighting their crucial role as an intermediary between theory and practice (Kearney, Damron, and Sohoni 2015). The work of Kearney, Damron, and Sohoni (2015) further provides a heuristic framework for the involvement of project managers in team development, initially providing strong team direction through their leadership position which the students gradually take ownership of themselves as their work progresses. This process allows students to recognise the importance of teamwork through improving their ability to communicate, set expectations and support one another (Fajarillo, Moussa, and Li 2021). Such examples are beneficial when managers simply act as **mediators of team dynamics** (Lescott and Tevaarwerk 2022) without being overly casual and not task specific in their interactions (Lucietto et al. 2017; Presler-Marshall, Heckman, and Stolee 2022). Furthermore, when applied in team-based design work the presence of project managers aids in mitigating performance costs associated with teamwork through fostering higher levels of semantic similarity (Gyory, Cagan, and Kotovsky 2019). Thus, it is necessary to consider how to best implement project managers or **mentors** within team-based programs, considering their role as a mediator between educators and students, instilling leadership structures and their importance as well as lessening the prevalence of performance costs.

4.4 TEAM CLIMATE AND CULTURE

Team climate and culture dictates how a team organises themselves, manages work efforts and forms norms. Oftentimes this involves pedagogical activities involving goal setting, team expectations and time management thereby precipitating the need to synthesise these findings in a way that presents educators with an overarching heuristic with which to implement teams with healthy cultures and climates.

Team climate and culture has proved to be an influential factor for team creativity and innovation (Hülsheger, Anderson, and Salgado 2009; Peretz, Levi, and Fried 2015; West 2002). Climate refers to “the set of norms, attitudes, and expectations that individuals perceive to operate in a specific social context” (Pirola-Merlo et al. 2002). Culture refers to beliefs, values, and ideologies shared by members of an organisation or discipline (Schneider, Ehrhart, and Macey 2011). Careful consideration should be given to ensure our engineering team projects opportunities and team environment encourage our students to value **innovation** and **collaboration** not only as a starting process but throughout the implementation process and communication of project **progress**. A unique benefit of this approach to teamwork would be the inclusion of team members belonging to diverse engineering **disciplines**. We are aware that this might be a very challenging logistic approach, however, if we merge concepts, theories, and approaches from multiple disciplines, as well as the principles, practices, and structures of different cultures we develop models that address team members’ vision, participative safety, task orientation, and support for innovation.

Team norms or expectations are critical first steps in instilling a healthy team culture (Løvold, Lindsjørn, and Stray 2020) and is something that is taught widely to varying degrees of success. Integration of team contract drafting as part of broader instruction regarding team management and leadership has been seen to reduce conflict whilst improving motivation, even distribution of workload, satisfaction and responsibility (Pertegal-Felices et al. 2019). Furthermore, when students are prompted to scaffold how they plan to resolve conflict within their teams in conjunction with creating a team contract, similar teamwork skills development is observed in addition to higher levels of trust and conflict resolution (Abreu and Read-Daily 2020). Students struggle however, when creating their own team norms and expectations during the early stages of their project citing difficulties regarding knowing their team members and specific requirements of their project (Presler-Marshall, Heckman, and Stolee 2022). Ultimately student construction of team norms and expectations through generating team contracts is associated with student teamwork skills development across the board. There are however some important pedagogical considerations that should guide this practice. Students should be given some explicit instruction regarding the necessity and purpose of these contracts as well as being given the opportunity to understand their project requirements and fellow team members before undertaking this task.

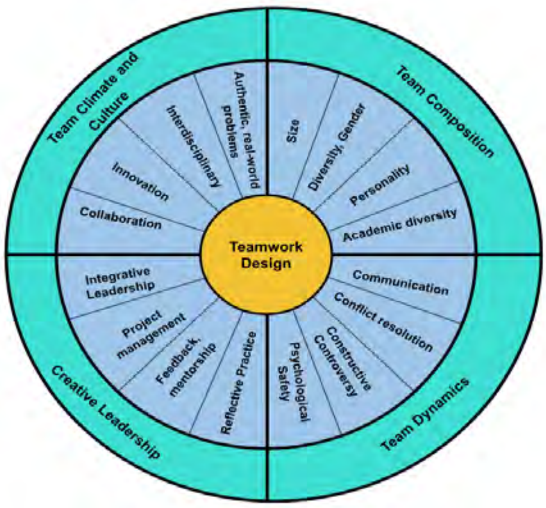

Fig. 1. Teamwork Skills Development Conceptual Framework

5 CONCLUSION

Sustainable development challenges are strongly connected to **increased complexity and integration challenges** (Phillips, Harrington, and Srai 2017). To address these challenges, we will need to lead our student teams across all disciplines in embracing the inherent complexity of the task, using it as inspiration to develop innovative and practical solutions. Further, as educators, we will need target aspects that consider the need to embrace this complexity and influence team effectiveness: *team composition, team dynamics, creative leadership and context (climate and culture)*. As this starting point of this research, will provide a clear framework for improving team collaboration and effectiveness *with the context of sustainable development in mind,* adding significant insights to the results provided so far by our research. Therefore, we recommend explicitly studying and optimising: 1) team composition; 2) team dynamics; 3) creative leadership; 4) team climate and culture. Figure 1 summarises the elements that will be considered in developing and refining our framework, based on further investigations.

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TEACHERS' REFLECTIONS ON THEIR EXPERIENCES TEACHING INTERDISCIPLINARY PROJECT-BASED COURSES

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ABSTRACT

In project-based, interdisciplinary engineering courses, teachers face the challenge of not only imparting technical knowledge but also facilitating effective project- and teamwork. In this study we conducted a thematic qualitative analysis of 11 teachers' reflections on interdisciplinary project-based learning (PjBL). The results show that teachers appreciated PjBL as a means to motivate students and that one challenge was handling differences in terms of student disciplinary background. While most teachers did not see a need for further training, teachers who did identify such needs also seemed to already apply a wider range of PjBL teaching strategies. We discuss the implication of our findings for both practitioners and researchers.

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1 INTRODUCTION

Over the last two decades, engineering education has increasingly been applying more active, student-centered, and collaborative learning methods. Project-based learning (PjBL) is one approach often chosen because it resembles the engineering profession and confronts students with real-world problems that must be addressed in teams, often across disciplines (Kokotsaki 2016, Mills and Treagust 2001). Furthermore, PjBL offers opportunities for graduates to develop 21st century skills, professional and transferrable skills, like creative thinking, communication, problem solving, and understanding of the social context of engineering. (Andrade 2016).

Previous research has shown that despite several reforms in engineering education, CDIO, PBL, PjBL (Crawley et al. 2007, Mills and Treagust 2001), these have not yet resulted in a systemic change (Mitchell, 2019). One reason could be that teachers experience challenges preventing them from engaging in PjBL despite the benefits for student learning (Kokotsaki et al. 2016). Some of these challenges include embracing a new role as a teacher (Hmelo-Silver et.al., 2007), designing project-based teaching, fear of not covering enough technical or disciplinary content (Hung 2011), and tension between theory and practice (Crawley et al. 2007).

Additional challenges appear when courses are interdisciplinary, engaging student teams across study programs (Kjellberg et al. 2015). These challenges include the university organisation and the teacher role, not only as course examiner but also as project manager, team facilitator, and student mentor. Previous research has suggested that in an interdisciplinary course context, the teacher team need to cover not only the disciplines involved, but also specific interdisciplinary teacher competence (Van den Beemt et al. 2020). Other required teaching skills are communication, leadership, project management and group dynamics (Kokotsaki et al. 2016). Hence, interdisciplinary PjBL requires teachers, who come from traditional engineering disciplines, to teach in a way that they in many cases have not experienced themselves. While there are many studies that highlight the multiple benefits of PjBL in engineering education (Andrade 2016, Hmelo-Silver et al. 2007, Kokotsaki et al. 2016, Mills & Treagust 2003), there is a dearth of studies on how teachers address, and cope with these challenges and reflect upon their experiences (Mitchell 2019).

This study aims to explore teachers' experiences of and reflections on teaching collaborative interdisciplinary project courses with diverse project groups in a context where teachers might have little experience and education with PjBL but where the university has adopted a major change within its education. Tracks, a ten-year initiative started in 2019, aims to encourage teachers to design and offer interdisciplinary, collaborative, project-based courses, closely connected to current research, industry, or the wider community. The 3, 7.5 or 15 credits courses are based on proposals submitted by self-formed teacher teams of varying sizes across disciplines. All courses are electives and available to bachelor and master students as well as to professionals. The courses aim to be interdisciplinary in terms of the projects' topic and scope, and student and teacher backgrounds, although mostly within STEM and particularly engineering disciplines. Currently there has been more than 500 students active within Tracks, taking part in one or more of the so far 25 offered courses. Student numbers within a course vary between 5-40 and they work in teams of 2-6 where the methods for forming teams vary between courses and are decided by theTracks course teacher.

Research questions: How do teachers support students in content learning and collaborative project work? When teachers evaluate the outcome of project-based courses, what aspects do they pay attention to? What training or support do teachers perceive they need?

In this text, we will consistently use the term "interdisciplinary," even though the teachers in this study employed a range of practices, including cross- and multidisciplinary approaches (Meeth 1978).

2 METHODOLOGY

A two-part questionnaire was distributed to 27 teachers teaching different PjBL courses within the Tracks initiative. The first part of the questionnaire addressed background and motivation to engage in PjBL, and the second asked reflective questions concerning how teachers scaffolded students' content and collaborative learning; what worked well in their courses; what challenges they met; what changes they wanted to implement; and finally, what support they need to continue teaching project-based courses. We received 11 responses, on which we conducted a thematic qualitative analysis (Braun & Clarke, 2006). First, the responses to each prompt were coded inductively by the first author, paying attention to teachers' individual experiences. This resulted in a large number of codes that were discussed and revised together with the second author. Second, the whole material was coded looking for common themes in teacher responses across the prompts resulting in three overarching themes.

The responding teachers were diverse in form of gender and nationality, two females and five non-Swedish. Their previous experiences within project-based teaching and learning were primarily based on BSc and MSc theses supervision and small project courses and most lacked experiences of interdisciplinary teaching. Two teachers mentioned more than 10 years' experience of PjB teaching, although most of the respondents were not that experienced. All respondents have fulfilled the university's requirements of 15 credits of training in teaching and learning in higher education, including a mandatory course in diversity and inclusion, but no obligatory course in PjBL.

3 RESULTS

The results from the first part of the questionnaire shows that teachers were motivated to engage in project-based learning because it is fun, inspiring, and motivating for both students and teachers: *"(...) an interesting way to teach"*. Furthermore, teachers were motivated by the opportunities to let students work with open-ended problems, link innovative research to education, and explore topics outside of core curricula. Two teachers valued the opportunity to start a new course in the shorter time that Tracks can offer, compared to what is needed within an established program.

Through the analysis of the responses to the second, reflective part, we saw the following overarching themes emerge: (1) where teachers invested their effort in supporting learning before, during and after the project course; (2) what they paid attention to when reflecting on their teaching; and (3) what changes they wanted to implement, including their need of (further) training and/or support.

3.1 Where are teachers investing their effort in supporting learning?

Teachers' strategies for investing their effort in project-based teaching were distributed on a spectrum between two course designs. The first one was to divide the course into two parts, where the first part was aimed at knowledge acquisition via lectures, seminars, or workshops. The second part consisted of industry or research related project work, where students were expected to apply the knowledge from the first part. Seven teachers used this approach, and it was predominantly chosen by teachers teaching courses that introduce students to a specialized knowledge area.

In the second course design, the course consisted only of project work and students were expected to acquire the knowledge needed to address the project task themselves, guided by teachers. This course design was predominantly chosen by teachers with more broad, general, and interdisciplinary project courses, where students chose their own projects based on a general theme rather than within a specialized area.

Across all course design types, there were several teacher approaches to support students' collaborative learning in their project- and teamwork. One aspect of this was how teachers to a varying degree controlled how students formed project groups. At one end of the spectrum, four teachers let students form groups entirely by themselves. At the other end, two teachers created as diverse groups as possible based on a set of criteria: disciplinary background, gender, interest, and scheduling. Finally, four teachers shared the responsibility of forming groups with students by letting them choose projects based on interest and adjusting the groups from there.

Ten teachers stated that they did not use specific models for the students to learn how to manage the project, process and define their roles in the team. Two teachers mentioned implementing course activities about project management, group dynamics, diversity and inclusion, and how to work in an interdisciplinary team. Two other teachers worked with reflective individual assignments. One of these teachers described this as: *"...a short reflection on the project progress and one's role in it. We hope that this will contribute to the project management-related learning objectives."* However, none of the teachers expressed that they had specific requirements for students to define and plan their project. Neither did they follow-up in any other way than via supervisor meetings and one expressed instead "*...students have to figure it out by themselves".*

Interestingly, among the seven teachers implementing a divided course design including lectures, seminars, and workshops, only two mentioned facilitation in project management or group dynamics. However, most teachers mentioned varying degrees of supervision to facilitate the project work. One teacher reported: *“Project management and teamwork was mainly facilitated by the main supervisor keeping track of the project and making sure that all students participated and found a good role in the project team”.* However, only one teacher reflected on how the supervision worked: “*What I have experienced very critical for a good result is how to manage a balanced supervision where the supervisor is neither too detailed nor too vague in the instructions.”*

3.2 What do teachers pay attention to when reflecting on their project-based teaching?

When considering teacher reflections on what they experienced went well, challenges they met and future changes they would like to implement, three subthemes emerged: project outcomes, diverse student groups, and students' knowledge backgrounds.

In the subtheme **achieved project outcomes,** four teachers explicitly mentioned that their student teams finalized their project, delivered satisfactory results, and produced well-written reports and presentations. None of the 11 teachers expressed any student team failing their project. Three teachers related the achieved outcomes to their course design; that introduction lectures and other activities successfully supported learning, and the application of knowledge in a project. One teacher related the success of their course to the opportunity of offering a variety of project topics based on real-world problems. Another one stated: *“My overall impression with teaching the project-based teaching Tracks course is positive, all students have applied specifically to this course and are motivated. The projects I use have been designed to allow students to use their respective backgrounds to go deeper into specific areas of the course. In my course the projects compliment the more general lectures and material in course in a good way.”* Furthermore, one teacher mentioned “... *at least one of the projects led to real-world implementation in industry and employment for one of the students.”*

In the subtheme of **diverse student groups,** teachers evaluated the outcome in terms of the student body taking the course. Two teachers expressed that they were happy with the mix of students, and one of them stated: “... *with good projects and good supervisors this diversity can strongly benefit the projects and the learning outcomes.”* At the same time, another teacher mentioned being impacted by cultural differences, for example in different student groups’ ways of asking questions. While one teacher shared that their students formed diverse groups without any intervention from the teacher team, another mentioned challenges in recruiting a diverse interdisciplinary student group since the Tracks courses are not well known in the educational program organisation. With few students and some dropouts, group projects were difficult to achieve, even more so diverse groups. Finally, two teachers saw less, or no, effects or issues related to diversity aspects like gender, age, or nationality.

In the subtheme **students' knowledge background,** seven teachers expressed that their greatest challenge has been the diversity in student knowledge level and background. Two of the seven teachers shared that they consciously tailored the lectures and other learning activities to the diverse disciplinary and broad educational background of the students. Another started with a quiz to identify differences and designed specific learning activities for those not having the prerequisites needed for the project. One teacher reported adjusting project scope, goals, deliverables, and boundaries to the students' background and interest. Interestingly, one teacher reflected: *"Some students were unhappy that the background knowledge of their teammates was much less than their own. Next year we'll maybe create more homogeneous groups."*

3.3 Future changes and perceived needs of support and training

When asked about what they want to change in their future teaching, five teachers planned to adjust their courses, although project outcomes were successfully met. One teacher wanted to increase facilitation of teamwork using a student group contract in the project start discussing roles and responsibilities, teamwork climate, decision-making and conflict resolution. Furthermore, the same teacher wanted to implement continuous peer assessment to support the students during project work. Another teacher mentioned adjusting course length, based on student feedback, to concentrate the project work during shorter time, and use the available makerspace, *"(...) to get better collaboration and learning cross groups (...)".* One teacher wanted to include more hands-on activities and study visits, and yet another an exchange with student groups within the same topic in a different context at another institution.

Of the eleven responses, only two teachers expressed specific needs of further training in project-based teaching and learning. One teacher wanted to improve their leadership skills to manage student project process better, and the other requested a "*pedagogical course joining outcomes from project-based teaching in different disciplines",* since project-based teaching differed between disciplines.

Four teachers mentioned that they have sufficient knowledge already, and one of them shared that it was being part of a well-connected teacher team that inspired and developed their teaching skills. Three teachers mentioned missing the collegial discussions they had in the required teaching and learning courses and wanted to see opportunities for these to continue. One teacher shared that in their department, they have several collegial discussions on project-based learning since their research and education is often connected to industrial development performed in team-based projects. Another teacher mentioned: *"I don't feel I need training, but best practice examples from other courses are always welcome."*

4 DISCUSSION

We set out to study teachers' experiences with teaching interdisciplinary project-based courses with diverse student groups. Our research questions were: How do teachers support students in content learning and collaborative project work? When teachers evaluate the outcome of project-based courses, what aspects do they pay attention to? What training or support do teachers perceive they need?

We got 11 teacher responses from the questionnaire; hence this qualitative study does not aim to get generalizable results. Rather, the open question design aims to saturate the range of perspectives among teachers. Still, we do believe that our results are transferable to universities in similar contexts with a limited experience of systematic interdisciplinary project-based teaching.

In general, teachers recognized and motivated their project-based teaching with key benefits that coincide with the project-based learning literature. These benefits include enhanced student motivation, better application of interdisciplinary theoretical and practical knowledge through authentic work- and research-related problems, and the development of essential generic and transferable skills (Shin 2018, Kokotsaki 2005).

Related to support of students' content learning, teachers chose course designs with varying degrees of openness with some focusing entirely on project work, but most adding more traditional lecture- and/or seminar-based activities, coinciding with findings by (Hung 2011). Interestingly, we were able to identify a link between the course content and the learning design, where more specialized research-based or industry-connected courses tended to utilize traditional methods to a higher degree compared to more broad and general courses. It appears that in these courses, teachers used lectures and seminars as a strategy to level the knowledge base among students before or during the project implementation. One interpretation is that these courses have knowledge specific learning objectives, like introducing a particular technology, and thus less effort can be put into training of generic and transferable skills to conduct interdisciplinary, collaborative projects. Courses also varied in their degree of student self-directed learning. While PjBL models typically stress a high degree of student autonomy (Hung 2011), this leads to the discussion of the role of enhanced self-regulated learning skills, which is an outcome of PjBL as a teaching approach. But these skills are also a pre-condition for students to effectively engage in PjBL, and that needs to be supported by the teacher and the learning design (English & Kitsantas 2013, Van der Beemt et al. 2020).

While teachers typically put a lot of effort into content learning in their course design, it appears that they paid less attention to questions of whether and how to scaffold collaboration during the project work. No explicit support was given for the definition and planning phase of the project, except for regular supervisor meetings in some cases, or how to monitor and evaluate their learning as a group. Furthermore, very few teachers report that they use models for project and team facilitation. Rather, an unstructured approach where students "need to figure it out themselves" appears to be the standard. While these kinds of "desirable challenges" (O'Connell et al. 2021) can foster student learning and problem-solving capabilities, we argue that a full hands-off approach can be problematic, particularly in interdisciplinary, diverse groups. This concern is partly supported by our results; although teachers homogeneously assessed their course results as very positive, their evaluations primarily pay attention to project outcomes, not the collaborative learning outcomes. Thus, it is left to chance that the group composition, individual management and regulation skills of its members result in high quality learning.

While researchers and the teachers in this study see group diversity in general as beneficial to student learning (Bergman et al. 2023), many teachers found it challenging to create learning benefits in project teams of students from different disciplinary backgrounds. If not adequately supported, there is a risk that avoidance strategies by both teachers, e.g., through forming homogenous groups, and students, e.g., by splitting tasks, to maximize independent work without joint monitoring, compromise the expected learning benefits of interdisciplinary PjBL (O' Connell et al. in review). Thus, instead of leaving collaboration to chance and assuming that the expected benefits of collaborative learning will emerge, we suggest that interdisciplinary diverse student groups in particular benefit from scaffolding, explicitly addressing aspects of group dynamics, project management and social regulation of learning. Research shows that students need help in forming diverse groups, both in terms of cultural and disciplinary background but that such groups are likely to be more creative, dynamic, and productive (Rientes et al. 2014). However, the success of diverse groups is more dependent on scaffolding, especially during the project start up (Bergman et al. 2017).

We noted that teachers, when asked about what training they need, focus on collegial discussions. Very few teachers see a need for formal training in how to support student collaborative learning or teamwork. This might be due to teachers not being aware of the resources and research that exist on how to support PjBL. Interestingly, those who reported a need for further training, also used a wider range of scaffolding strategies in their project-based course design.

In conclusion, the overall positive teaching experiences reported here can serve as encouragement for other teachers to engage in interdisciplinary PjBL. As shown, a variety of learning designs can thereby be effectively used to engage students in PjBL. Based on our results though, we call for more attention to the group aspects of PjBL. It could be argued that teachers just need further training or education, but as our result show this is not easy when teachers themselves do not see the need. Hence, we need further research into best practices and interventions to scaffold collaborative learning, to support teachers in developing the necessary awareness and skills to facilitate students' project- and teamwork, particularly in interdisciplinary project courses with diverse student groups.

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LEARNING THROUGH SCREENS DURING COVID-19 CRISIS: FORESEE TOMORROW'S EDUCATION BY ANALYZING YESTERDAY'S SETBACKS AND BARRIERS

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ABSTRACT

This paper aims to enrich the state of the art on engineering and management learning and education by shedding light on the barriers encountered during the COVID-19 crisis due to the imposed digital transformation. Our research question is: what were the barriers encountered in remote and hybrid learning during pandemic experiences and what lessons can be drawn for higher education in the context of Problem-Based Learning (PBL)? This paper aims to enrich the debate on how digitalization impacted the learning and teaching experience in teaching modules traditionally achieved face-to-face.

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To investigate our research question, we adopted an abductive, quantitative, and qualitative approach through a case study methodology. Based on our literature review we proposed a five-fold barriers taxonomy: (a) technical, (b) anthropologic, (c) epistemic, (d) didactic, and (e) financial barriers faced during the technology-intensive learning experience. These barriers have been audited in the context of a French engineering school. The analysis of the barriers confirmed by the field study made it possible to highlight three must-do actions: (A) develop the ability to learn, (B) develop agility, and (C) empower teachers and students. These actions aim to ensure better quality and resilience of the future learning process in the post-covid world.

1 INTRODUCTION

Well before the COVID-19 crisis, people were immersed in a digital lifestyle where IT is embedded in everyday activities (Devaux et al. 2017). In the United States of America, over half of the children (53%) own a smartphone by the age of 11, and 84 % of teenagers have their own smartphones (Rideout and Robb 2019). In France, 38% of people admit that they sometimes consult their screen during family meals (ELABE 2019). Digital transformation plans were already on the agenda before the pandemic situation. The economic and health impacts of the pandemic crisis have made them a top priority (Vollmer 2020). According to a study carried out by McKinsey & Company (LaBerge et. al. 2020), COVID-19 has accelerated the adoption of digital technologies by several years. The modern world has turned to digitalization and digital tools to cope with lockdowns and to reinvent an environment of collaboration (Liu and Shirley 2021). Since then, in some ways, screens have become inescapable.

The measures adopted due to the pandemic crisis have profoundly challenged the learning and teaching processes (Almarzooq et. al. 2020). The implementation of pedagogical approaches where formal and informal exchanges are very important to drive deep learning has been undermined (Greenberg and Hibbert 2020). Some curricula have been challenged more than others due to the experimental (Greenberg and Hibbert 2020) and the technical dimension of targeted competencies fulfilled traditionally by face-to-face learning and learning by doing, generally done in classrooms. It was typically the case for pedagogical approaches such as Problem-Based Learning (PBL). In this approach, the learning process occurs through prepared situations or real situations where the students are highly engaged (Prince and Felder 2006).

The intensive digital transformation of the learning experience due to remote and blended learning has raised many questions. This paper aims to enrich the state of the art in engineering and management learning and education by shedding light on the barriers encountered during the COVID-19 crisis due to the imposed digital transformation. Our research question is: what were the barriers encountered in remote and hybrid learning during pandemic experiences and what lessons can be drawn for higher education in the context of Problem-Based Learning (PBL)?

This study has a threefold objective. The first fold is to identify, understand, and structure the barriers to learning created by the COVID-19 crisis. The second fold is to enrich the empirical knowledge on the subject by providing elements of feedback based on the case study of a French engineering school. The third fold is to propose, on the basis of this feedback, recommendations to practitioners and decision-makers to ensure better quality and resilience of the future learning process.

Our paper is organized as follows. Section 2 provides insights into barriers to Learning in a digital context imposed by COVID-19 through a literature review and proposes a five-fold barriers taxonomy. Section 3 presents the methodology adopted in order to collect, analyze and propose feedback in the context of the studied case study. Section 4 exposes the results of the audit and contextualization of the identified barriers and the proposed must-do actions.

2 BARRIERS TO LEARNING IN A DIGITAL CONTEXT IMPOSED BY COVID-19

A huge amount of research has already focused on the barriers to learning generated by the forced digitalization imposed by the pandemic situation. Using these studies, we proposed a five-category taxonomy:((a) technical, (b) anthropologic, (c) epistemic, (d) didactic, and (e) financial) for the barriers to learning found in our literature review (see Fig. 1). These barriers can be influenced by other phenomena imposed by the pandemic such as lockdowns, and social distancing.

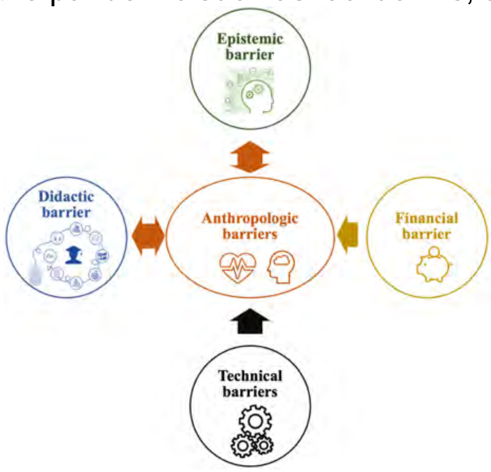

Fig. 1. Proposed taxonomy for the learning barriers in a digital COVID-19 imposed context

2.1 Technical barriers: Internet and software access

Technical problems related to handling platforms and internet connectivity appeared as one of the main sources of stress during exams in COVID-19 periods (Elsalem et. al. 2020) and more generally in the learning experience during the pandemic situation (Vielma and Brey 2021 ; Mohapatra 2020 ; Lanthony et. al. 2021). The poor internet access can make it difficult for teachers and students to access software, share video, or even browse data. It can be a huge problem for them when working remotely, resulting in difficulties to contribute to teamwork. The shift from a well-equipped environment to working from home provoked a feeling of frustration, mainly because of the abruptness of the transition (Thornton 2021). Indeed, while working at home is a “new normal” brought by COVID-19, technical issues can jeopardize the learning experience and turn it into a nightmare. Financial issues can worsen the effect of the technical barrier due to a lack of funds to acquire the required equipment.

2.2 Anthropologic barriers: Well-being, psychological and physical conditions

COVID-19 triggered an exceptional response that affected society's foundation to inhibit contagion (Brammer et. al. 2020). The transformation imposed by the

pandemic situation has impacted individual and population mental health (Galea et. al. 2020). It has put great pressure on the academic ecosystem (Brammer and Clark 2020), especially on students. “Levels of stress, anxiety, loneliness, and depressive symptoms among students have increased since the coronavirus crisis” (Zerhouni et. al. 2021). This pressure has undermined the well-being of stakeholders in the learning process not only because of the abruptness of the transformation but also because of the exceptional workload generated for teachers and learners. The latter had to cope with the challenges of academic learning in tandem with family obligations, financial burdens, and increasing workload due to the pandemic situation (Mohapatra 2020 ; Asgari et. al. 2021 ; Saw et. al. 2020 ; Kooli-Chaabane et. al. 2021). Vielma and Brey (Vielma and Brey 2021) highlight that students have experienced a reduction in their motivation and focus to fulfil their classwork.
The question of privacy has been raised by public opinion (Hunter 2021 ; Jenkins 2020). When working or learning time is done on private territory, private aspects can be exposed in front of colleagues or schoolmates. Constant task switching between work and private activities can be mentally tiring (Kossek 2020). This oscillation can make it hard to concentrate on work. This confusion has been the source of discomfort.
Moreover, technology-intensive learning can cause dehumanization of the learning process. The mental health of students came into the public debate in France some months after the beginning of the pandemic. It led the minister for higher education to recommend a full face-to-face 2021-2022 academic year. Official bodies like the French Consultative Commission for Human Rights (FCCHR) pointed out in a report in 2021 “the urgent need to strengthen health services, in particular mental health, within higher education institutions”. In the same report, the FCCHR highlights the risk of a dehumanized learning (CNCDH 2021), focusing on the lack of facial contact, with the camera frequently turned off for technical or personal reasons.
It should be noted that most of the students and almost all teachers still in the higher education system in 2023 suffered from these difficult conditions and still have to cope with them during the process of building the post-covid education world.

2.3 Epistemic barrier: The lack of digital skills

During the COVID-19 outbreak, both teachers and students struggled with adapting to remote learning due to the lack of digital skills (Saw et. al. 2020). Indeed, the lack of digital skills can prevent from accessing and being part of digital education (Grand-Clement et. al. 2017). Teachers currently identify the use of digital technologies as one of the areas where they are in greatest need of professional development (Devaux et. al. 2017 ; Mohapatra 2020). The ability to learn and to teach in a digital environment requires not only a minimal mastering of collaboration tools such as Microsoft Teams, Google Meet, and learning platform such as Moodle but also requires the ability to deal with online information. In a world that is rapidly embracing digital technology, students and teachers need to be able to gather and use online information critically (OECD 2015). Gaps in the digital skills of teachers and students must be considered to reduce the wedge between expectations and reality.

2.4 Didactic barrier: Failing to choose an appropriate educational scenario

From objectives to learning outcomes, from learned competencies to assessment, from colors of interfaces to the learning experience, the educational scenario of a teaching module is a whole system to be imagined and set up in a coherent logic.

Integrating digital tools is more than another refit in the learning context. Indeed, the forced remote conditions during the pandemic showed that in a digital environment, thinking about the educational scenario is even more important than in traditional learning (OECD 2015). The articulation of different learning modes (asynchronous and synchronous) seems to be a key success factor of the learning experience in the context of intensive use of digital technologies (Vielma and Brey 2021). Failing to choose an appropriate articulation between the pedagogical approaches, the communication strategy, and the learning modes leads only to the addition of 21st-century technologies to 20th-century teaching practices. This failure will dilute the effectiveness of teaching.

2.5 Financial barrier: The costs of the digital transformation

Digital transformations are expensive (Wade and Shan 2020). A global approach involving public authorities and private sectors should be conducted to study the coverage of these costs. During COVID-19, the first impediment to working from home arose from the need for material support. Indeed, the question of who bears the cost of setting up the integration means of digital technologies to implement remote work was raised (Thornton 2021). The intensive use of new technologies for work and learning can price out individuals who cannot afford the technologies (Grand-Clement et. al. 2017). In the learning context, these costs may not be the burden of educational organizations alone but shared across ministries to better reflect the reality of the needs for digital learning throughout a person’s life (Grand-Clement et. al. 2017).

3 METHODOLOGY

We adopted a quantitative and qualitative abductive approach through a case study of a French public engineering school, with around 600 learners divided into three levels and where practical works account for 47% of teaching hours and 28% of the teaching hours are based on the problem- and project-based learning approaches. To address our research objective, we developed a three-phase methodology. The first phase aimed to identify, understand, and structure the barriers to learning created by the COVID-19 crisis. This work allowed us to propose a taxonomy for the identified barriers presented in the second section of this paper. In the second phase, we audited and contextualized the identified barriers. The outcome of this phase was a matrix where the presence of the identified barrier categories is checked and contextualized.

Table 1. Overview of the used surveys

Survey period	May 13-28, 2020	Feb. 8-March 1, 2021	May 26-June 4, 2021
Department in charge	Learners’ Affairs Department (LAD)	Educational Innovation Unit (EIU)	LAD and EIU
Objectives	Feedback on the remote learning experience	Feedback on teaching practices in the COVD-19 period	Feedback on the learning experience in the COVD-19 period
Target	Learners	Teachers	Learners
Target size	419	48	610
Number of answers	315	26	212
Answers (%)	75%	54%	35%

Table 1 presents an overview of the list of the surveys conducted from May 2020 to June 2021 to audit and contextualize the learning barriers, knowing that the situation

evolved from fully imposed remote activities from March to June 2020 to a mix of fully online and blended learning from October 2020 to June 2021.
The third phase of our methodology consisted of a 75 minutes workgroup. This workgroup was twofold. The first target was to grasp the teachers' feedback on the barriers encountered during the pandemic crisis. The second target was to formulate propositions of must-do actions.
The workgroup was composed of 8 participants (teachers and teacher-researchers). The sample of participants was constructed to meet three criteria: (1) having more than six years of teaching experience, (2) having taught at least for three years before the COVID-19 crisis, and (3) being involved in a learning process with a strong digital dimension using PBL approach.
The discussions and exchanges were conducted according to a methodology based on a focus group (Simon 1999 ; Kitzinger 1994) for collecting qualitative data (Wilkinson 1998). Focus group is particularly adapted to explaining and exploring survey results (Kitzinger 1995). The work group was conducted using a guide where a predefined script is detailed. We opted for detailed note-taking due to the high risk of inhibition created by the potential recording of exchanges. Each of the authors made an individual content analysis. Three debriefing meetings were planned to compare individual analyses, formalize conclusions, and refine our proposal.

4 RESULTS

4.1 Audit and contextualization of the identified barriers in the literature

We fully observed the appearance of three (technical, anthropological, and didactic) of the five identified categories of barriers. The two remaining categories were partially observed. When a barrier was observed, we proceeded to its contextualization with facts from our field observation and data collection. Table 2 gives an overview of the results of the audit and contextualization of the identified barriers in the literature.

Table 2. Matrix barriers, audit, and contextualization

The identified barriers	Audit	Contextualization for students	Contextualization for teachers
Technical barriers	Yes	▪ Connection problems: 37% in 2020 (†) and 36 % in 2021 (*) of the interviewed learners reported that they had an "insufficient" internet connection ▪ Hardware problems: In 2021, 57% of the interviewed teachers reported that between 5% and 20% of their students were limited by their computer's performance (•) ▪ Lack of a well-equipped environment: 36% in 2020 (†) and 31 % in 2021 (*) of the interviewed learners reported that they had no dedicated place to work at home	▪ Connection problems: In 2021, 38% of teachers quoted connection issues among the issues they have faced (•)
Anthropologic barriers	Yes	▪ Additional workload: In 2020, 56% of the interviewed learners had the feeling to work "more" or "much more" remotely than face-to-face (†). This rate decreases to 22% in the hybrid situation in 2021 (*) ▪ Reduced exchanges and social interactions were reported by students' spontaneous statements and several free written statements made by teachers about students (•)	▪ Additional workload: In 2021, 46% of the interviewed teachers pointed out the problem of work overload due to extra time needed to create or adjust their teaching materials. 40% of the interviewed teachers said that they recorded part of their courses (•) ▪ Impression of working all the time: In 2021, 27% of the interviewed teachers emphasized multiple and simultaneous requests from students, which increased their work time. 72% of the teachers interviewed quoted that they had to rephrase the students' questions and interventions to be considered by all the students (•) ▪ Reduced work exchanges and social interactions: In 2021 58% of the interviewed teachers quoted isolation among the issues they faced (•)

Epistemic barrier	Yes, partially	▪ Spontaneous statements from teachers about a systematic waste of time during online teaching to deal with problems related to the students' lack of digital skills.	▪ Spontaneous statements from teachers about their difficulty in putting their teaching resources online via platforms and during online collaborative work due to their lack of mastery of digital tools such as Microsoft Teams, Google meet and Zoom Meetings
Didactic barrier	Yes	▪ Necessity to be more autonomous and to change the way of work - In 2021, 28% of the interviewed learners declared that they had difficulties to organize their work time (*) - In 2021, 15% of the interviewed learners declared that they had difficulties to find resources and to do work on online platforms (*) - In 2021, 35% of the interviewed learners declared that they had difficulties to work independently and 34% of the interviewed learners needed more assistance from teachers (*)	▪ Necessity to rethink the educational scenario to better integrate remote learning - In 2021, 62% of the interviewed teachers reported that they would continue to change some of their teaching resources after the lockdown periods. 36% of the interviewed teachers quoted that they are ready to adjust between 25% and 100% of their teaching resources (•) - In 2021, 65% of the teachers said that they would create new "short contents" if "recording, editing and content creation equipment were available" (•)
Financial barrier	Yes, partially	▪ Inability to afford adequate equipment: Two internet connection keys and 23 personal computers have been made available by the school to learners	▪ Additional expenses: In 2021, 62 % of the interviewed teachers reported that they would need a new headset (•)

(†): Survey (May 13-28, 2020), conducted among learners by the Learners' Affairs Department
(*): Survey (May 26-June 4, 2021), conducted among learners by the Learners' Affairs Department and the Educational Innovation Unit
(•): Survey (Feb. 8-March 1, 2021), conducted among teachers by the Educational Innovation Unit

4.2 Workgroup's feedback and proposition of three must-do actions

The participants in the workgroup admitted that the possibility of partly monitoring the learning process of PBL remotely allows to increase the frequency of exchange with students. This leaves room for students' greater autonomy. As the student manages the teacher solicitation rhythm, he becomes an actor in his learning process.
One of the main convergence points which emerged from discussions was that the students who had experienced the start of their problem-based work group in the classroom kept the principles of exchange and mutual aid between groups in the intensive digital context. Nevertheless, the members of the groups who started their projects during the lockdown tended to remain self-contained and not collaborate or exchange with other groups. The participants believe that the lack of interaction has affected the students' awareness of their competencies and their self-assessment progress. The effectiveness of learning via screens seems to depend on the sequence of the educational scenario. In other words, face-to-face session to stimulate the intra-group connection is a success factor in the implementation of the problem-based learning pedagogical approach in digital context learning.
Participants claimed that customizing the process based on the user needs is a key success factor for learning in a digital context process. Creating the same learning process for all to increase accessibility may hamper inclusivity.
The work group identified three must-do actions to contribute to ensuring better quality and resilience of the future learning process: (A) develop the ability to learn, (B) develop agility, and (C) empower teachers and students. The participants highlighted that decision-makers must invest in capacity development and change management to develop these three actions in the post-covid world.

Develop the ability to learn

In our complex, modern, and rapidly changing world, the one true constant is change. Individuals and organizations need to be ready to face any wave of change or disruption at any time. The first key asset to be developed to face a world shaped by fast-changing digital technologies is the ability to learn and adapt its competencies. Learning how to learn is a meta-skill that organizations, individuals, and, more particularly, teachers need to face the continuous change in their environment. Teachers have the responsibility to ensure the adequacy of the students' competencies to the need of the workplace. They themselves must keep their competencies up to date probably more than any other profession.
Developing students' ability to learn by providing resources to be consulted individually has two advantages. Firstly, it allows students to have access to the

resource at their own pace. Secondly, it gives them a sense of responsibility in the learning process. Developing the ability to learn can lead to a more customized learning process if the educational scenario is well-planned. Participants in the workgroup insisted heavily on the fact that the actions to be done and the objectives to be reached by the students must be set in advance to avoid “losing” them. They claimed that the risk they fear the most is that students spend their time zapping from one resource to another. Indeed, building a learning mindset is not an easy task. It can also trigger fear and temptation to fall back on familiar solutions that worked before if the learning process has not been well planned and instrumented.

Develop agility

The participants highlighted that to exist in tomorrow's world, we need agility to cope with change. Agility will allow the needed flexibility and pragmatism to adjust to the expected or unexpected changes in the shortest time span. Indeed, the teachers reported that the health crisis has forced the educational community to be agile. They have had to step out of their comfort zones and explore other forms of teaching. The pedagogical proposals offered to students are now much more varied. Throughout the week, they will follow classical courses, problem-based teaching, flipped classes, and autonomous teaching sessions. Capitalizing on it to improve agility is mandatory. For instance, the creation of video nuggets allowing the technical handling of software and intuitive procedure to explain how to take control of students’ computers remotely are possibilities cited to foster agility.

Empower Teachers and Students

The participants in the workgroup highlighted that, in the learning process, empowering teachers and students is an important driver: it is vital that they must be given the means to become active agents for change. Teachers must go beyond just implementing technological innovations and design innovative educational scenarios. Students must be put at the heart of the learning process.

Participants also highlighted that the technical dimension of learned concepts and didactic difficulties led them to rethink their way of approaching the notions with the constraint of learning in a digital context. They, thus, had to create new supports or make the existing ones evolve by considering the prism of the student alone facing the learning resource. An effort to integrate all the notions given usually orally in the classroom was necessary. Many teachers felt the need to integrate videos or hybrid solutions (written resources and links to video nuggets) in their educational scenario during and after the COVID-19 crisis. They emphasized the great need for support in planning and instrumenting during the educational scenario upgrade process. Involving users (teachers and students) in the implementation of the change increases their sense of belonging and commitment which is a form of collective empowerment.

5 SUMMARY AND ACKNOWLEDGEMENT

Our methodology allowed us to find out three out of five barriers defined in the presented taxonomy. We audited them by analysing students and teachers feedback. From that, we proposed a set of must-do actions in order to develop the ability to learn, develop agility, and empower teachers and students.

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EMOTIONAL LABOR EXPERIENCED IN TEAM-PROJECTS: A COMPARISON OF ENGINEERING AND HOSPITALITY STUDENTS

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ABSTRACT

Team projects are an integral part of the student learning experience. However, emotions can significantly affect student performance during team projects. Students use different emotion regulation strategies, such as surface-acting (emotive dissonance) and deep-acting, to regulate their emotions during team projects. These strategies can result in different 'emotional labor' levels, leading to emotional exhaustion, dissonance, and burnout. The level of emotional labor may also vary depending on the discipline and the nature of the work. This study thus investigated if engineering and hospitality students have different levels of emotional labor in team projects. Data were collected using a modified Emotional Labor Survey from 90 engineering and 174 hospitality students in team projects at two European universities. The results showed a statistically significant difference in emotive dissonance between engineering and hospitality students. Engineering students experienced more emotive dissonance than hospitality students, suggesting they may need more support in regulating their emotions during team projects. These findings have important implications for educators. By understanding students' different emotional labor levels, educators can design interventions to help students regulate their emotions and improve their performance in team projects. Further research is needed to investigate emotional labor in engineering education.

1 INTRODUCTION

Team projects are essential for students to acquire the necessary skills for their profession in the future. Thus, it is crucial to ensure all participating students have a meaningful and enriching experience, gaining valuable skills, knowledge, and personal growth through team projects. However, many factors can affect students' performance in these processes (Isaac et al. 2023). Indeed, emotions, as well as cognitive, motivational, attitudinal, cultural, social or behavioral factors (Rasmussen and Jeppesen 2006), may be one of the factors that significantly impact student performance (Barczak et al. 2010) in team projects. For example, shared, positively valued emotions within teams enable engagement, cooperative team behavior, social integration, creativity, decision-making, and performance, while shared, negatively valued emotions limit them (Barsade and Knight 2015). Emotions, thus, can play a critical role in engineering team dynamics (such as emotional support) and the learning process of the teams.

However, both positive and negative emotions could be fruitful for the teams. For example, students must possess a minimum level of social collaboration emotions, such as warmth, which play an essential role in shaping the collective emotional experiences of the team. A sense of security is also necessary for students to make mistakes without fear of significant consequences. Further, power dynamics can be experienced emotionally, such as anger, and these emotions can intersect with differences in gender, culture, or ethnicity (Tormey 2021). On the other hand, although team projects allow students to acquire some critical skills, working on team projects may also intersect with students' personal and professional identities. For example, a study found that female students are less likely than male students to believe their ideas are respected in engineering student teams (Aeby et al. 2019). Such power dynamics could negatively affect the quality of team performance and students' emotional experiences in teams. In short, working on team projects is an emotional task that requires expressing, displaying, regulating, and managing all these emotions.

However, it is crucial to acknowledge that students might not feel at ease expressing their emotions due to the common cultural display rules requiring different emotional displays from different social groups, and cultures also value emotional displays differently depending on group membership (Bericat 2016). For example, in general, in Western cultures, and in particular in the engineering field, emotions are frequently viewed as a hindrance to rationality (Roeser 2012), and "being an engineer" means to be "non-emotionally demonstrative - trust in logic, analysis, and reason" (Godfrey and Parker 2010, 14-15). This view of rationality and the culture of engineering can result in the imposition of strict feeling rules that restrict the range of emotions one can express or display without experiencing significant social consequences such as a decrease in status and power (e.g., anger may be seen as righteous indignation in men or as a lack of rationality in women from ethnic minorities ['angry black woman' trope]). Hence, instead of displaying their feelings precisely, engineering students can fake, hide or suppress their emotions (Grandey 2003), resulting in 'emotional labor.'

Emotional labor is "the management of feelings to create a publicly observable facial and bodily display" (Hochschild 1983, 7). It is a term that describes exhibiting emotions that align with social and cultural norms and expectations, even when those emotions do not match individuals' true feelings. This term also involves changing one's emotions to better conform to those social expectations. There are several types of emotional labor (Chu and Murrmann 2006; Diefendorff et al. 2005). However, the two most commonly discussed are surface-acting and deep-acting (Grandey 2003). Surface-acting involves modifying one's outward display of emotions to conform to social norms or expectations without necessarily changing how one feels internally. For example, students might put on a polite smile while dealing with difficulty working on a team project, even if they feel frustrated or angry. On the other hand, deep-acting involves trying to change one's inner feelings to match the emotions expected in a given situation. This can be more challenging and can require a greater degree of effort than surface-acting. For example, students might try to cultivate empathy and compassion for a teammate in distress. In other words, students can work to get themselves to feel the emotion they are expected to display. As a result, students may have different emotional labor levels depending on the strategy selected, leading to various levels of emotional exhaustion, dissonance, and burnout (Grandey 2003).

The level of emotional labor may also vary depending on the discipline and the nature of the work (Humphrey 2021; Serebrenik 2017, Wang et al. 2019). For instance, hospitality students are often trained to perform emotional labor to provide high-quality service (Chu and Murrmann 2006; Xiong et al. 2023). They often receive training in social interactions, inter and intrapersonal, and communications skills as a part of their curriculum, as their work involves frequent interactions with customers or guests. Hence, they may know more about how to manage their tone of voice, body language, and facial expressions to convey a welcoming and professional demeanor, resulting in more emotional labor. On the other hand, engineering students have traditionally been stereotyped as working in a technical field (Lönngren et al. 2021) that does not principally depend on making clients and colleagues feel particular emotions (and consequently, may be assumed to not involve high degrees of emotional labor). They thus may receive less (almost no) formal training in similar issues in their education, as their work is more focused on technical skills and scientific problem-solving. It is worth noting that although engineers also receive training that is supposed to support their "professional development" through the development of professional skills, often called transversal skills (Kovacs et al. 2020), the development of such skills – even though they exist – is minimal, and often dismisses the importance of emotional dimension. Thus, engineering students may be more likely to engage in emotional labor to regulate their relationships with teammates or teachers while working on team projects, which involves managing conflicts, emotions, expectations, deadlines, stress levels, and effective communication and collaboration. The emotional labor of engineering students may also be higher due to the lack of cultural bridges between home and engineering culture (Godfrey and Parker 2010), the culture of competitiveness in engineering (Hacker 1981), and the culture of hypermasculinity and the importance of displaying behaviors and values that align with hypermasculinity (Leyva et al. 2016). These factors can give rise to more emotional labor experienced by engineering students.

In short, engineering and hospitality students may differ in their experiences and engagement in emotional labor. However, it is worth noting that although many studies focus on emotional labor in hospitality, there is a lack of studies addressing emotional labor in engineering (Buzzanell et al. 2023; Houben and Wuestner 2014; Serebrenik 2017). To our knowledge, no study has focused on differences or similarities in the emotional labor of those two groups. This study thus aims to investigate to what extent the levels of emotional labor experienced in team projects differ in a sample of engineering students who are in technology-oriented roles and, therefore, may not see emotion regulation as a skill and hospitality students who are in service-oriented roles and thus may see emotion regulation as a critical skill. The research question we sought in this study was therefore as follows:

RQ. How do the levels of emotional labor experienced in team projects differ in a comparative analysis of engineering and hospitality students?

2 METHODOLOGY

2.1 Method

In this study, we administered an Emotional Labor Survey to the engineering and hospitality students involved in team projects. We used a modified version of the Emotional Labor Survey developed by Diefendorff et al. (2005). The survey includes 14 items under the three factors: Surface-acting (7 items), Deep-acting (4 items), and Naturally Feeling (3 items). Also, it included 11 demographic questions related to participants' age, gender, level of education, main fields, as well as why and how they participated in the teams, and the duration of interactions in the teams, etc. The survey employed a 5-point Likert scale. The lowest score was 1 (never), and the highest was 5 (always) for an item. Students took the survey online on a purpose-designed platform. The testing procedure usually lasted five to ten minutes.

2.2 Participants and Data Collection Procedures

Data collection started in late 2022 at two European universities (a large technical university and an international hospitality management school) and is ongoing. Ethical approval for this study was obtained from the institutional research ethics committees. Since teaching takes place in English at both universities, and since the original questionnaire was in English, we used the English-language version of the questionnaire, which was administered online. So far, 90 engineering and 174 hospitality students in team projects have participated in the study. *Table 1* shows the distribution of various demographic and other variables among two distinct student groups. Of the 264 partipants, 34.10% (N: 90) were engineering students, while 65.90% (N: 174) were hospitality students. In total, 47.35% of the respondents were female, 34.09% belonged to the age group of 21-23, and 45.45% were in their 1st year of a Bachelor's program. In total, 38.64% of students had been a member of that team for over three months, 60.61% chose to join the team while the teams were forming, and 71.97% reported that their interactions with team members lasted more than 5 minutes during team meetings. Among the engineering students, 58.89% identified themselves as male, 40.00% as female, and 1.11% identified with a gender other than male or female. On the other hand, among the hospitality students, 45.40% identified themselves as male, 51.15% as female, and 3.45% identified with a gender other than male or female. Most students in both institutions (72.22% and 54.60%) chose their teams. An important difference between the two institutions is the duration of interaction during team meetings: Half of the engineering students (51.11%) surveyed reported that the normal interaction timeframe for them was more than 5 minutes, while this rate was 82.76% for hospitality students.

Table 1. Demographics of the participants

Variables		Engineering Students (N:90)		Hospitality Students (N:174)		In total (N:264)	
		N	%	N	%	N	%
Gender	Female	36	40.00	89	51.15	125	47.35
	Male	53	58.89	79	45.40	132	50.00
	Other	1	1.11	6	3.45	7	2.65
Age	18-20 years	33	36.67	88	50.57	121	45.83
	21-23 years	38	42.22	52	29.89	90	34.09
	24-+ years	19	21.11	34	19.54	53	20.08
Educational Level	1st Year Bachelor	24	26.67	96	55.17	120	45.45
	2nd and 3rd Year Bach.	29	32.22	46	26.44	75	28.41
	Post-Bach.	37	41.11	32	18.39	69	26.14
Chose Team Members	Yes	65	72.22	95	54.60	160	60.61
	No	25	27.78	79	45.40	104	39.39
Membership Duration	1 month	20	22.22	43	24.71	63	23.86
	2 months	18	20.00	17	9.77	35	13.26
	3 months	14	15.56	50	28.74	64	24.24
	4 months	5	5.56	44	25.29	49	18.56
	5-+ months	33	36.67	20	11.49	53	20.08
Duration of interactions	Less than 5 minutes	44	48.89	15	8.62	59	22.35
	More than 5 minutes	46	51.11	144	82.76	190	71.97
	No Answer	0	0	15	8.62	15	5.68

3 RESULTS

3.1 Scale Validation

In this study, we focus on how the levels of emotional labor experienced in team projects differ in a comparative analysis of engineering (technology-oriented roles) and hospitality (service-oriented roles) students. Before making any comparisons, we performed some statistical analysis for the scale since we used it in a different field and modified some words in the items (e.g., we changed the word 'customers' to 'teammates'). The Kaiser-Meyer-Olkin (KMO) test showed that our data was suited for scale validation. The parallel analysis suggested two components and the Kaisers criterion of an eigenvalue of 1 confirmed this. These each had a clear structure with high-loading weights on a single component. Consequently, we deleted the two surface-acting items and reverse-coded the three items of the 'Naturaly Feeling' factor. *Table 2* shows the factor analysis results on the remaining 12 items. The two factors identified are (i) 'deep acting' (following the lead of Chu and Murmann [2006]), who similarly found a two-factor structure for emotional labor) and (ii) 'emotive dissonance.'

Table 2. Scale Validation (N: 264)

Items**	Emotive Dissonance (8 items)***	Deep Acting (4 items)***
I fake the emotions I show when dealing with teammates	0.83	
I put on a mask in order to display the emotions I need for the team	0.78	
I show feelings to teammates that are different from what I feel inside	0.74	
The emotions I show teammates come naturally*	0.74	
The emotions I express to teammates genuine*	0.70	
I just pretend to have the emotions I need to display for my team.	0.68	
I fake a good mood when interacting with teammates	0.65	
The emotions I show teammates match what I spontaneously feel*	0.65	
I work at developing the feelings inside of me that I need to show to teammates		0.76
I work hard to feel the emotions that I need to show to teammates.		0.73
I make an effort to feel the emotions that I need to display toward other teammates		0.71
I try to experience the emotions that I must show to teammates		0.67
Cronbach's α	.87	.71
Variance explained (%)	35.93%	18.50%
Eigenvalue	4.31	2.22
Kaiser–Meyer–Olkin measure of sampling adequacy	.85	

Note: * Reverse coded. **All items derived from Diefendorff et al. (2005) *** Factor loadings less than .40 have been removed for ease of reading.

The emotive dissonance dimension had eight items with strong factorial reliability (Cronbach's alpha = .87).The deep-acting dimension contained four items with acceptable factorial reliability (Cronbach's alpha = .71). The two-factor solution accounted for 54.43% of the total variance, with the emotive dissonance dimension accounting for 35.93% and the deep-acting dimension accounting for 18.50%. All items had loadings greater than .60 and loaded well onto their corresponding dimensions. As a result, the instrument was satisfactorily modified. Then we performed data analysis for comparisons of groups.

3.2 Comparing the levels of emotional labor experienced in team projects between engineering and hospitality students

We performed descriptive statistics for each factor and group. Then, we conducted independent two-sample t-tests or ANOVA on the differences in each mean for the groups. We marked the results in tables that are significant at the p = .05 level. *Table 3* provides means and standard deviations, while *Table 4* shows the comparisons for each group.

Table 3. Means and standard deviations for each of the factors by groups

	University	N	Mean	Std. Deviation	Std. Error Mean
Emotive Dissonance	Engineering	90	2.55	.76	.08
	Hospitality	174	2.34	.77	.06
Deep Acting	Engineering	90	2.90	.78	.08
	Hospitality	174	3.04	.85	.06

As *Table 3* shows, both groups had moderate levels of emotional labor (means from 2.34 to 3.04 on a 1-5 scale). In other words, both groups had emotional labor. However, engineering students (M = 2.55, SD = .76) had a higher level of emotive dissonance than hospitality students (M = 2.34, SD = .77), while hospitality students (M = 3.04, SD = .85) had higher level of deep-acting than engineering students (M = 2.90, SD = .78). To reveal if there were statistically significant differences between the groups' means, we performed an independent samples t-test (*Table 4*).

Table 4. Independent samples t-test for each of the factors by groups

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence	
Emotive Dissonance	.12	.74	-2.06	262	.040*	-.21	.10	.40	.01
Deep Acting	1.23	.27	1.25	262	.213	.13	.11	.078	.35

*Statistically significant difference p <. 05

Table 4 shows that there was a statistically significant difference in emotive dissonance between the engineering and hospitality students [Engineering (M = 2.55, SD = .76 and Hospitality (M = 2.34 SD = .77) groups; t (262) = -2.06, p = .040)]. However, there was no statistically significant difference in deep-acting between the engineering and hospitality students [Engineering (M = 2.90, SD = .78) and Hospitality (M = 3.04 SD = .85) groups; t (262) = 1.25, p = .213)].

3.3 Comparing the levels of emotional labor experienced in team projects between engineering and hospitality students in terms of some variables

Dividing the students into groups based on their gender identity yielded no significant difference concerning the emotive dissonance [Female (M = 2.37, SD = .74), Male (M = 2. 43, SD = .81), and Other (M = 2.70, SD = .78; (F (2, 263) = .68, p = .506)] and deep-acting [Female (M = 2.93, SD = .82), Male (M = 3.04, SD = .84), and Other (M = 3.18, SD = .70; (F (2, 263) = .70, p = .496)]. *Tables* 5a and 5b show the results.

Table 5a. Means and standard deviations for the factors by gender identity

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
Emotive Dissonance	Female	125	2.37	.74	.07	2.24	2.50
	Male	132	2.43	.81	.07	2.30	2.57
	Other	7	2.70	.78	.30	1.97	3.42
	Total	264	2.41	.78	.05	2.32	2.51
Deep Acting	Female	125	2.93	.82	.07	2.79	3.08
	Male	132	3.04	.84	.07	2.89	3.18
	Other	7	3.18	.70	.27	2.53	3.83
	Total	264	2.99	.83	.05	2.89	3.09

Table 5a. Comparisons (ANOVA) for the factors by gender identity

		Sum of Squares	df	Mean Square	F	Sig.
Emotive Dissonance	Between Groups	.82	2	.41	.68	.506
	Within Groups	157.29	261	.60		
	Total	158.12	263			
Deep Acting	Between Groups	.97	2	.49	.70	.496
	Within Groups	180.45	261	.69		
	Total	181.42	263			

In our research, an analysis of the participants' emotive dissonance and deep-acting concerning additional demographic variables yielded no significant results. In other words, dividing the students into groups based on their age, educational level, choosing team, membership duration, and duration of interactions resulted in no significant difference between the emotional labor of engineering and hospitality students.

4 CONCLUSIONS

We designed this study to reveal to what extent the levels of the emotional labor of engineering and hospitality students working on team projects differ. The question was, "How do the levels of emotional labor experienced in team projects differ in a comparative analysis of engineering and hospitality students?"

The findings of the study revealed that engineering students demonstrated similar, even higher, levels of emotional labor to those of hospitality students, indicating that contrary to common beliefs, engineering students engage in emotional labor in team projects. This is an important finding as it challenges the perception that engineering study is solely focused on abstract technical tasks and does not require emotions. However, it is worth noting that engineering students, in general, received less training that can be related to emotional labor than their hospitality counterparts. Furthermore, there is also evidence that hospitality students have higher levels of emotional intelligence than students in other disciplines (Darioly 2019). As a result, engineering students may rely on less sophisticated and more emotionally costly strategies when performing emotional labor. This might explain why engineering students exhibit higher levels of emotionally dissonant labor than hospitality students. Another possible explanation for the higher levels of emotionally dissonant labor among engineering students might be related to the timeframes of their interactions. Engineering students focus mainly on the technical aspects of the projects, which require more rapid decision-making and problem-solving while working on team projects. As it is seen in *Table 1*, of the engineering students surveyed, 51.11% reported that their normal interaction timeframe was more than 5 minutes, whereas, for hospitality students, the percentage was much higher at 82.76%. As a result, the use of emotionally dissonant regulation strategies by engineering students may be influenced by the relatively shorter timeframes of their team interactions, although further investigation is necessary to validate this assumption.

In summary, the study demonstrates that emotional labor is an essential aspect of team projects for engineering students. While they exhibit similar (even higher) levels of emotional labor compared to hospitality students, engineering students may require additional training and support to regulate their emotions in team contexts effectively. As the different emotional labor strategies have different impacts on individuals' mental health, burnout, and performance, it was crucial to understand first to what extent engineering students (compared to other students in various disciplines) experienced emotional labor. Thus, in this study, we aimed to reveal the level of emotional labor that engineering students experienced in team projects. Given the study's preliminary findings, educators should focus more on courses and interventions designed to enhance engineering students' transversal or emotion management skills.

4.1 The next steps of the study

In this study, first, quantitative survey data were gathered from the two distinct populations of students to determine where there might be differences in intragroup emotional labor. Then, a second qualitative stage will be undertaken to determine potential reasons for their intrateam behavior through interviews with a smaller sample. Data collection is currently in progress. The results will provide valuable insight into emotional management, likely identity construction, and its relevance in discipline-specific intrateam interaction in under- and post-graduate engineers and hospitality students. Also, although demographics such as culture and ethnicity were not included in this study, they are important factors related to emotional labor and could be included in future work in this area.

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PLANNED, TAUGHT, LEARNT: ANALYSIS OF TRANSVERSAL SKILLS THROUGH CURRICULUM USING PORTFOLIO

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ABSTRACT

There is an everlasting effort in education to successfully ensure that the intended learning objectives are clearly taught and effectively learnt at the end of the educational cycle. This has been especially difficult in teaching and learning complex sets of competencies, for example, transversal skills in domains such as engineering education. Yet, studies focusing on transversal skills often address student learning outcomes, but rarely how teachers teach them, and even less so how they are represented in the written curriculum.

In order to create a more comprehensive understanding of how transversal skills are communicated, taught and learnt in engineering education, we designed a qualitative case study with a focus on teaching and learning transversal skills. The data was collected from five distinct sources within one master course. This included examining the written curriculum as presented in the course syllabus, the taught curriculum with data from the teacher interview and teaching materials, and the learnt curriculum coded from student portfolios.

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In our results, we reflect on alignments, gaps and potentials in teaching and learning transversal skills. Alongside, through our case we argue that alignment in learning intentions and outcomes is stronger due to using a training portfolio and explicitly requiring reflection as part of the assessment, which does not prevent other learning outcomes from evolving spontaneously. We also discuss suggestions for portfolio design and its use in teaching and learning transversal skills in engineering education.

1 INTRODUCTION

Whenever a course is put in place, there is a learning objective that a teacher expects the students will achieve. While there is no way of controlling what students actually learn, careful pedagogical planning of a constructive learning environment is a way to support reaching the intended learning objective. Systematic, intentional construction of the parts of the pedagogical input combined with analysing of the educational outcomes falls under the scope of an aligned curriculum [1, 2]. The appeal for curriculum alignment has been growing since the 1950s [3], and studies were particularly focused on achieving learning objectives that are intangible, implicit and difficult to teach.

In many cases within the constructive curriculum alignment literature, the portfolio has been used as an integrated tool that supports the alignment between taught and learnt [2, 4]. In addition to that, the engineering education portfolio has been used to support the teaching of transversal skills [5]. Some of the barriers to introducing the development of transversal skills are indeed related to the pedagogical capacity of creating learning environments, as well as appropriately following the development of skills and their assessment. In most cases, attention is given to what and how students learn [6, 7], and in rare cases how teachers teach the transversal skills, or how they are proposed in course documents and syllabi.

With this perspective, we aimed at discovering how transversal skills are embedded in different aspects of the curriculum and what are the elements that make the translation from intended to learnt curriculum achievable. To understand this, we particularly look into the use of a portfolio as a teaching tool that connects the intended learning objectives to student learning outcomes.

In this paper, we present an analysis of a single course as a case study targeted to explore how the intention to teach certain skills leads to what students learn, and how the use of a portfolio as an assessment tool supports this process. We, therefore, ask two questions:

1. How are transversal skills represented in the intended, taught and learnt curriculum?
2. What is the role of a portfolio as a tool to reflect on and assess transversal skills?

Our intention to research transversal skills and the use of a portfolio in this case study connects to the difficulty of teaching and assessing transversal skills. The intention to understand different aspects of the curriculum connected to transversal skills follows the idea that educational experience is not a single point of analysis, but a system that needs to be comprehensively understood. In other words, by looking only at the student learning outcomes we might not be able to understand the intended environment and input that students received for reaching the learning outcomes.

In the following, we briefly reflect on two theoretical aspects that support this study, the curricular research and portfolio literature, followed by a swift description of our methodology, a presentation of our results, and a brief summary in the conclusion.

1.1 Curriculum alignment

Curriculum alignment refers to a process that ensures courses and programmes offered by an institution are consistent with its objectives and outcomes. The aligned curriculum is the degree to which learning goals are represented in student learning outcomes and assessments. The goal of achieving alignment is to ensure that students are equipped with the knowledge, skills and abilities needed to succeed in their careers, as envisaged by the institution.

There are different aspects of an aligned curriculum, including alignment within the institutional offer often referred to as curricular coherence, as well as alignment with industrial standards and accreditation requirements. In this paper, we refer to curricular alignment as a course-level coherence that ensures the intended learning objectives are synchronous with student-perceived learning, as in Figure 1.

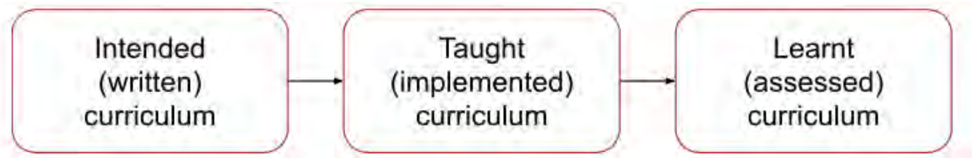

Figure 1: Simplified presentation of curriculum alignment

In this domain, Biggs and Tang [2] have influenced the field by proposing constructive alignment of curriculum, which includes intended written curriculum, teaching activities that create learning opportunities, and assessment, both in terms of tasks and grades that define learning outcomes for students. Similarly to this, van den Akker et al. [8] note that it is difficult to make an exact translation from the intended to the learnt curriculum, pointing out that each educational stakeholder perceives the curriculum and their place in it in a slightly different way. In support of this, Wijngaards-de Meij and Merx [9] observed that the alignment is challenged by students' lack of awareness of their role in the learning process and their preoccupation with assessment. Tyler [3], known for introducing the idea of curriculum development, proposed a non-static model through which he offered four dimensions enclosed in questions for educational processes, including questioning the purpose of the institution, experiences that are to attain the purpose, organisation of activities and educational activities, and methods in determining achievement.

While the simplified triadic approach to curriculum alignment refers to three aspects, namely what is written in the curricular document, what is taught by the educator, and what is attained by the students, different terminology has been used in the literature explaining these three processes. In this paper, we use the *intended* curriculum, instead of *written* or *declared* to indicate what the educational intention was when designing the course. For the second aspect, we use the term *taught* curriculum observing it from a wide perspective of teacher's input, including lesson delivery, materials and teaching philosophy. And finally, we intentionally refer to the *learnt* and not *assessed* or *tested* curriculum. With this, we do want to point out that most literature on curriculum alignment focuses on assessment and not learning, as this is the regular educational cycle. For us, the term *assessment* was too narrow, hence our intention was to explore what students learn overall, rather than what they submit for the assessment.

1.2 Portfolio

In education and training, portfolios have been gaining prominence, particularly for their use in assessment. Portfolios support "a new perspective on learning since they document the learners' progress and evaluate with a variety of evidence how learner goals are attained, while at the same time providing an alternative for the growing dissatisfaction with the traditional and quantitative assessment" [10]. As the educational evidence on portfolios grew, so did the differentiation between types and uses, and as such Smith and Tillema [10] proposed a typology based on purpose and use, as depicted in Figure 2.

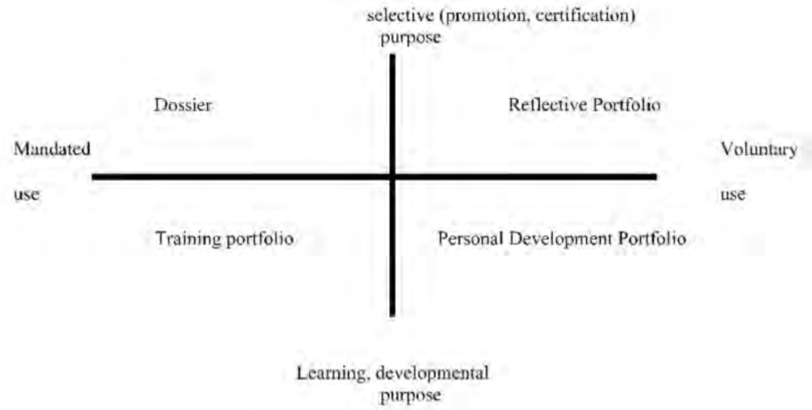

Figure 2: Different types of portfolios [10]

By understanding the different types of portfolios, educators can use them for their intended purpose.

Portfolios have, in general, been a useful tool for students' self-regulated learning and reflective thinking [11]. Regardless of the shape in which it is formulated, by directing students' attention to specific aspects of their learning experience, portfolios have the ability to illuminate certain aspects that might otherwise remain implicit or unrecognised during the learning process. In many cases, prompting questions serve as a starting point of reflection and they usually do not prevent students from describing their experiences more comprehensively and freely [12, 13]. Even when a portfolio represents a relatively low percentage of the final grade, students engage with the reflection beyond the course-specific technical knowledge. For instance, Dunsmore et al. [13] point out that although the focus of the course is on manufacturing processes, in their portfolios students reflect on the nature and importance of skills like communication, teamwork and collaboration in team projects. The authors also note that creating even a simple portfolio "provides an opportunity for reflection and articulation" of ideas and issues [13].

2 CONTEXT: HOW PEOPLE LEARN

The course, called How People Learn: Designing Learning Tools, which we selected for this case study belongs to the Social Studies and Humanities courses at EPFL.

The course is offered to first-year master students as an accredited elective two-semester course, and its design is based on mini-lessons tied with project-based learning through students working in teams. The course deliverables are a report and a portfolio, and student teams are supported through a set of on-demand coaching sessions with the teaching staff. Assessment is a mix of summative and formative, with technical report weighing 80% of the grade and portfolio the remaining 20%. In this study, we focused only on the portfolio that targets the development of transversal skills.

The portfolio type used in this course is a training portfolio according to Smith and Tillema's [10] typology. It is divided into 3 parts, the first corresponding to a reflection on the Interdisciplinary Project Management Questionnaire [14] that students are recommended to take at the beginning of the semester. The second part consists of reflective blocks with steering questions on creative thinking, documentation of processes, team communication, and management of divergent and convergent thinking. Each team member is responsible for completing one of the reflective blocks, after which the other team members provide their points of view. These reflective blocks are completed throughout the semester, and this part of the portfolio is not considered in the final assessment. The final part of the portfolio is the only part that is assessed and it includes a tabular summary of previous ungraded reflections, with a particular focus on the change of practice, and two reflective questions related to learning about group management and project management.

In completing their reflective blocks, students are guided by prompting questions and invited to record their meetings in order to source their thinking and reflections. In providing instructions for completing the portfolio, it is explicitly stated that the assessment will focus on the quality of students' reflections regardless of whether the desired learning is achieved or not. This means that the grade is given on the basis of the quality of student reflection, rather than the acquisition of a skill. This encourages students to present honest reflections, rather than create fictionalised attempts to satisfy the teacher's expectations.

3 METHODOLOGY

This research was developed as a case study of a single course involving three aspects of the curriculum and five sources of data. We used a qualitative approach in data collection and creation, as well as in our analysis and interpretation of our results.

3.1 Qualitative case study approach

Following Merriam and Tisdell [15]: "[a] *case study* is an in-depth description and analysis of a bounded system". The objectives of this research were to uncover aspects of the curriculum and the use of portfolios comprehensively through a single course which is why a case study approach was the most appropriate choice. While there are different types of case studies, our intention was to use "a qualitative approach in which the investigator explores a real-life, contemporary bounded system [...] through detailed, in-depth data collection involving multiple sources of information" [16].

In our research design, the bounded system is the course, and five sources of information address the three aspects of the curriculum, and the detailed in-depth data collection includes written curricular course documents, the IPMQ test and the structure of the portfolio, a teacher interview, and student input in their portfolios.

3.2 Data collection and analysis

In an attempt to comprehensively develop a case study, we collected data from five different sources corresponding to three aspects of the curriculum.

In terms of the intended curriculum, we used the course document that is publicly available online and provides a description of the course and the learning outcomes for the transversal skills. Since the institution has a framework for transversal skills which is used in course documents [17], we simply extracted the skills as they were presented in the document and classified them under the category they belong to.

To understand the taught curriculum, we collected data from three sources that we defined as important in creating learning incentives for transversal skills. In our first step, data was collected from a semi-structured interview with the course teacher. This allowed us to explore, through a conversational setting, the teaching and learning approach of the educator, their course philosophy and delivery. The interview was conducted by the lead researcher, Kovacs, transcribed, pseudo-anonymised and analysed by using the qualitative analysis software MAXQDA. The coding was done by the lead researcher, and an interrater exercise was performed by the second researcher, Milosevic, on about 20% of the interview segments. This allowed us to establish the validity of the coding process and discuss perspectives in the analysis. It was important for us to analyse the structure of the portfolio and the interdisciplinary project management questionnaire (IPMQ), both tools which guide students to reflect on and assess their skills. We thematically analysed the text in these documents, particularly focusing on transversal skills intended to be developed through the course. As the two main researchers, Kovacs and Milosevic, we looked at the course document and, in the first step, developed our individual analyses. In the second step, we deliberated on our perspectives in an attempt to generate a joint analytical conclusion.

Data related to the learnt curriculum were collected from the content in the 19 student portfolios spread across 5 groups. The course included 56 portfolios in total, however, we used only the data from the students belonging to the same group that consented to the study. The documents were assigned randomised identifying codes, and the raw data was split among the two main researchers, and separately manually coded. Prior to the coding process, we looked into nuanced conclusions from the teacher interview analysis, as well as the analysed structure of the portfolio and IPMQ. In particular, those initial steps in the analysis informed the construction of a codebook, and we applied a mix of deductive and inductive approaches in coding the content in portfolios to identify the concepts that might not have appeared before. Learning was “captured” as explicit and implicit mentions of transversal skills. The results were discussed between researchers and processed into the final visual representation.

3.3 Limitations

While this case study combines a rich tapestry of data to describe the alignment of the curriculum at a course level, we acknowledge that there are other elements of the curriculum that we have not taken into account at this point, such as the hidden curriculum. Furthermore, the elements we have chosen for the taught curriculum are limited to three aspects, and we accept that there are elements missing, such as observations of classroom teaching, documents and communication on the learning platform, slides shared in mini-lectures and student-teacher exchanges during the coaching sessions. All these elements contribute to the taught curriculum and such relevant data could be considered in further research. A similar limitation can be established for the learnt curriculum; we have explored the reflections offered by students in their portfolios, but potentially, further research could integrate ideas about transversal skills mentioned in the technical reports, which equate to a higher proportion of the grade, as well as observations of teamwork, their final presentations, and their discussions with teachers in the coaching sessions.

4 RESULTS

In this study, we focused on the alignment of the three aspects of the curriculum by using portfolios in learning and teaching transversal skills. We mapped our overall analysis in Figure 3 to visualise the alignment at specific stages and highlight the coherence and gaps.

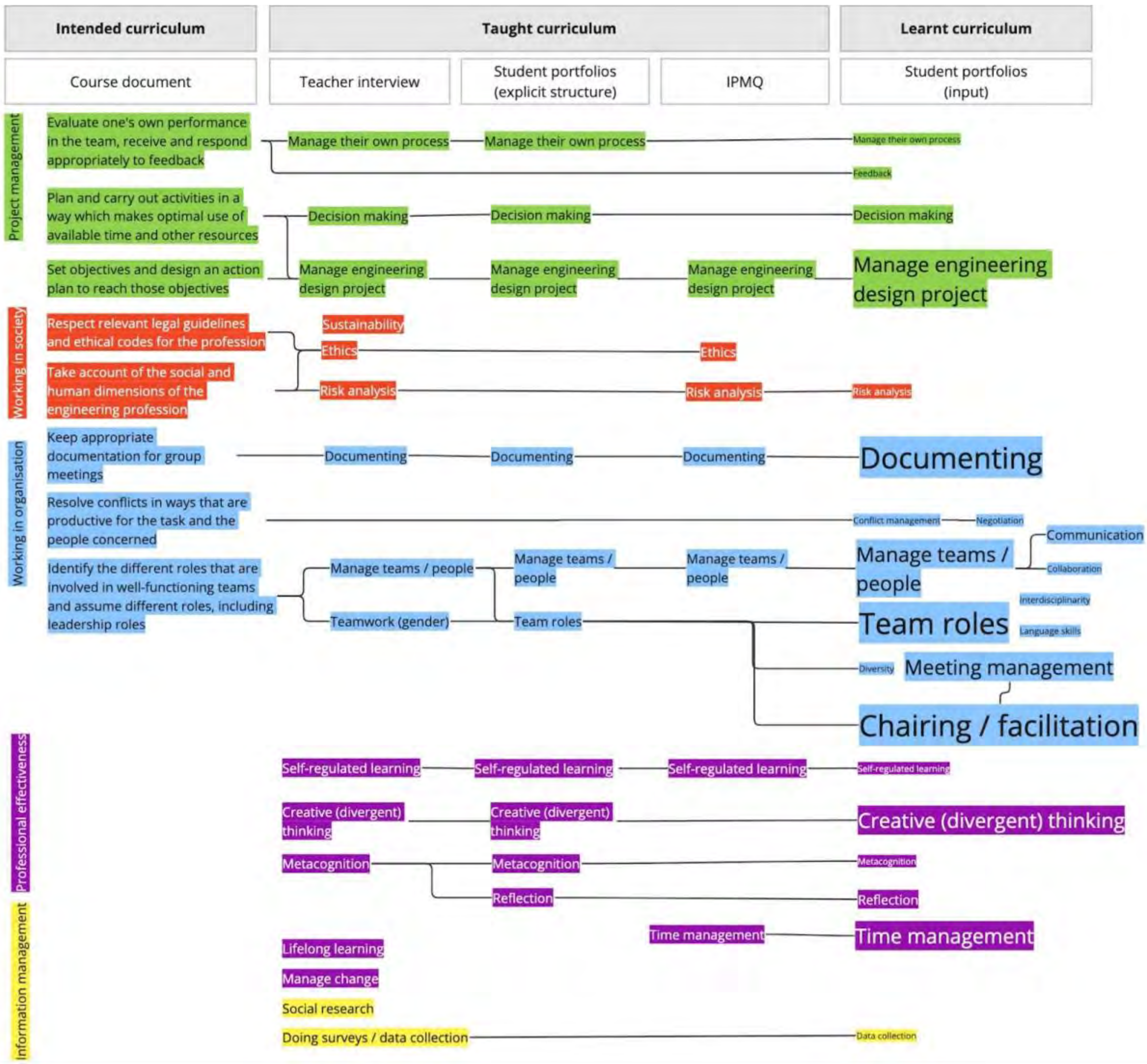

Figure 3: Visualisation of curriculum alignment

In reading this map, we point out several observations; each phrase or word in the map represents a transversal skill mentioned at a specific point of data analysis. In the first row (intended curriculum), the wording is richer and longer because it corresponds to the institutionalised transversal skill list that teachers use in constructing their course documents (see [17]). The colours of the map also correspond to how the transversal skills are grouped into five families, and these five competence families and 32 skills are pre-set by the institution.

Under taught and learnt curriculum, the wording is shorter and corresponds to inductive coding of the data collected from different data sources. We created connections between the phrases and words to indicate alignment between different curricular points. For instance, the first blue line (*documenting*) was present in all aspects of the curriculum we analysed. In the learnt curriculum, students mentioned some skills more than others, so we gave them different weights (four different font sizes) to explicitly show the amount of impact.

4.1 Intended curriculum

The most interesting observation about the intended curriculum is that we can see several transversal skills being taught and mentioned in student reflections, but not in the course documents. This is particularly visible in purple and yellow lines, which in the institutional skills families correspond to *professional effectiveness* and *information management* categories.

Another interesting observation is that some skills, such as *conflict management*, were mentioned in the course document, do not appear in the taught aspects, and then were occasionally found in the student reflections (blue second line). This leads to the assumption that, since the skill intended in the course document is not emphasised through the taught curriculum, it may have not been very effectively reflected upon.

4.2 Taught curriculum

The taught curriculum was analysed from three data points: teacher interview, portfolio structure and the IPMQ. It is interesting to observe that not all of these three aspects contain all the transversal skills mentioned, which might not also be necessary. What we can see, particularly with the first red line with *ethics* (Fig 3), is that even if a specific skill is represented in the course document and taught at some point in the curriculum, it may not appear in the learnt curriculum.

Similarly, as pointed out in the previous section of the intended curriculum, the taught input seems to be richer than the intended objectives listed in the course document. This misalignment is particularly prominent with skills in purple, i.e. *creative (divergent) thinking* and *time management.*

4.3 Learnt curriculum

At the point of the learnt curriculum, we can quickly observe that there are many more skills, especially in the blue category, than in the intended and taught curriculum. This shines a light on students' unintended learning through reflecting on their course experiences, but also shows that even if some skills are not represented in the intended or taught curriculum, they are not "prevented" either.

On account of skills weight (size of the font in Fig 3), our observation was that in many cases these were the skills that were more emphasised in teaching materials, particularly with the prompting questions in the portfolio. For instance, *documenting* skill was thoroughly addressed in one reflective block, hence it is not uncommon that students' attention would be focused on it. In the case of *team roles,* we see the same pattern, but also with additional aspects like *chairing/facilitation* and *meeting management*. This points to the potential of using portfolios for directing students to reflect on particular skills they gain through the course.

5 CONCLUSIONS

Research on aligned curriculum has the potential of opening the discussion on how efforts of teaching and learning skills at different stages of the curriculum are represented. In our case study, we reflected on how portfolios as an explicit demand for reflection can support the learning of transversal skills and as such we noticed where the alignments and gaps appear in the course design, delivery and uptake.

Biggs and Tang [2], as well as Tyler [3], remind us that constructive curriculum alignment needs to open questions, such as what is intended for a course or a programme, how will this be supported and scaffolded in different aspects of teaching, including assessment, and how will it be evidenced as a learning achievement. The use of portfolios has shown that attention can be specifically drawn to reflecting on certain skills, hence, making the intention explicit to the students [13].

Our case study shows that purposefully directing students' attention to reflect on skills they use through their project work can bring a better alignment between the intended and learnt curriculum, and support student learning. Preparing a portfolio structure that supports this reflective process leads to greater awareness of the specific skills. Setting an objective at the beginning and evaluating oneself at the end helps in understanding the learning journey, and potentially how it can be improved for and by the learner. We also notice that skills that were not intended or even taught still do appear in the learnt curriculum, most likely in connection to neighbouring skills, confirming that they are not prevented by the teaching approach nor by teaching tools presented in this case study.

On the translational side, the visual representation of the aligned curriculum can be a helpful tool to suggest how teachers can optimise their efforts for teaching and learning transversal skills. It gives a presentation about the places in the curriculum where a stronger emphasis could be made in terms of reflective questions, and what are the points missing in the initially proposed curriculum. We see great potential for this kind of research on a course level, but also beyond a single course - a larger analysis could provide input to a stronger alignment of the full corpus of courses at a programme level.

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SEARCHING FOR YOUNG TALENT: UNDERSTANDING INDUSTRIAL RECRUITMENT PRACTICES FOR HIRING ENGINEERING DEGREE APPRENTICESHIP STUDENTS

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ABSTRACT

This study aims to investigate industrial companies' recruitment practices and standards for hiring their engineering degree apprentices. We examine (1) how they find their future engineering degree apprentices, (2) their recruitment standards and (3) to what extent organisational characteristics shape their recruitment decisions.

To answer these questions we have carried out an online quantitative study, comprising exclusively closed questions, with the participation of workplace mentors of engineering apprenticeship students (n=70). Subsequently, we have conducted a descriptive statistical data analyse on SPSS.

Our results indicate that industrial companies find their engineering apprentices by means of students' speculative applications or via engineering schools which have already conducted their academic recruitment process. Surprisingly, technical knowledge or transversal competences have a limited influence on their recruitment decisions, but students' motivation and personal attitudes (e.g.: personal engagement, perseverance, adaptability) have a very marked, nearly decisive influence on their hiring choices. In addition, we have identified some slight differences between large international and domestic industrial companies' and SME's recruitment decisions.

Based on our results, we highlight the importance of collaboration between industrial companies and engineering schools in order to develop a more inclusive engineering apprenticeship recruitment process.

INTRODUCTION

Master's degree level apprenticeship programmes in French engineering schools, with the dedicated support of the French government, began in 1992 with the accreditation given by the CTI (Commission des Titres d'Ingénieur / French Engineering Accreditation Body) to just six selected institutions (Rouvrais et al. 2020). During the last decade, we have observed a steadily increasing interest in, and proliferation of, such work-based engineering training programmes, which are becoming more and more attractive to students desiring to engage in engineering studies. In 2021-22, more than 18.2 % of French engineering students were enrolled in one of the more than 280 (master's degree level) apprenticeship programmes proposed by French engineering schools (SIES 2022).

The recruitment of degree apprenticeship engineering students is a two-phase process composed of (1) an initial academic recruitment drive followed by (2) a workplace recruitment as the second phase. The academic recruitment process is mainly based on academic results (theoretical knowledge, technical and transversal competences) taking into consideration students' future career perspectives. After the validation of this first phase, enrolled students apply for apprenticeship positions in industry to find the most suitable workplace to complete their three-year master's degree apprenticeship studies. From the students' point of view, this second phase is widely recognised as a critical stage of the recruitment process (Drewery et al. 2022) as they are expected to find their future workplace on their own within a specified time-limit.

The workplace recruitment phase is also a critical stage from the point of view of their future employers, who naturally want to attract the most talented apprentices to reinforce the human capital of their various organisations. Despite the importance of this recruitment phase, in the academic literature there are few studies focusing on the employers' recruitment strategies and practices for selecting their degree apprentices. As far as we know, no previous research has investigated this question from the standpoint of employees in a French engineering education context. To fill this gap, our study aims to investigate industrial companies' recruitment practices and standards for hiring their degree engineering apprentices.

We propose the following research questions:

- RQ1: - How do industrial companies' recruit their engineering degree apprentices?
- RQ2: - What are their recruitment criteria and standards?
- RQ3: - To what extent do their organisational characteristics shape their recruitment decisions?

LITERATURE REVIEW

As reported by several authors (Fabian et al. 2023, Drewery et al. 2022, Protsch 2017) in other countries, the recruitment process of degree apprentices is quite like the regular graduate recruitment process involving a multiple stage selection process. To attract talented apprentices, the most commonly used recruitment method by employers is to post job advisements on their official websites. According to the findings of Drewery et al. (2022), student applicants seem to be most attracted to organizations where the employers express their commitment to the work-study programme and propose real opportunities. Fabian et al. (2023) analysed apprenticeship job advertisements for IT related industrial sectors in England and Scotland, taking into consideration the salary, required skills, and attributes of employers. Surprisingly, employers appear to look for the same transversal skills (the most appreciated are communication, problem-solving and interpersonal skills) and attributes for apprentice positions as for graduate positions. Other findings show that apprentice job advertisements put emphasis on the proposed training and learning developments but often omit important details concerning the related tasks. Concerning qualification requirements, employers require very similar qualifications for prospective apprentices and candidates from purely academic backgrounds. Also, technical competences are explicitly required in apprentice job advertisements, as well as prior professional experience (manly in lower lever apprenticeship positions).

In their qualitative study, Ruiz and Goastellec (2016) investigated the higher apprenticeship recruitment process from both student and employer standpoints in Switzerland. Their results confirmed that, for the employers, the level of knowledge ("savoir"), the professional experience, and the expertise ("savoir-faire") of student applicants are not considered to be the most important conditions for a successful recruitment - since all these competences are judged to have already been well-evaluated in academia. From the employers' point of view, the cultural capital ("savoir-être") of the student applicants is the most determinant recruitment condition. However, employers put different emphases on the various elements of social capital (ex.: attitude, motivation, interpersonal relationship, personal engagement and agency, anticipatory thinking, reflexivity, autonomy, self-management…) in line with their organisational context. These competences are often related to students' social status and developed in a "hidden curriculum" that could represent a source of social inequality in the recruitment process. A recent longitudinal study by Kergoat (2022) confirmed the presence of social inequalities in the employers' selections by highlighting the importance of social capital and, more specifically, family socialisation (and support) in the recruitment process.

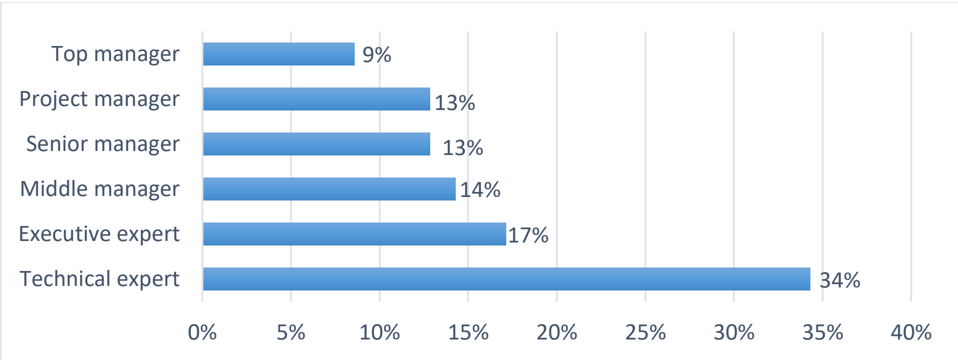
Concerning the influence of organisational characteristics, Protsch (2017) explored the effect of organisational size and private/public sector affiliation on the apprenticeship selection process in Germany. Her findings confirmed that student applicants are more likely to be invited for an interview when applying to larger organisations in the public sector than when applying to small organisations in the private sector. Also, applicants with lower academic ratings tend to have more chance of being selected by larger organisations. These findings indicate that larger organisations apply a more inclusive apprenticeship recruitment strategy.

METHODOLOGY

To answer our research questions, we designed an online quantitative survey with exclusively closed questions to facilitate further data analysis. This survey covered workplace mentors of post-graduate engineering apprentice students in industrial companies and included questions focusing on their (1) recruitment process and (2) recruitment standards. Before launching the online survey, we completed a pre-test process with five experienced workplace mentors who gave us their feedback. This enabled us to improve the survey design, especially regarding the formulation of several answers (adding short complementary explanations to avoid any possible confusion).

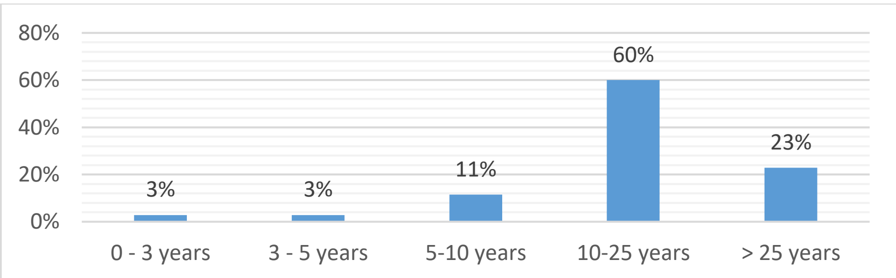
In accordance with our initial research design, we disseminated the online survey via email. In our covering message, the workplace mentors received detailed information about the survey objectives, the applied confidentiality policy, and the use of data exclusively for academic and research purposes, all before the start of the survey. However, several mentors contacted us saying that they would have liked to respond to the survey questions, but that they were unable to do so online because of the high security requirements of their organisations. Finally, due to this unexpected constraint, we sent out a paper version of the quantitative survey. We obtained a relatively high survey response rate of 52.63% (we invited 133 mentors and received 70 fully completed responses) with 57 responses online (81.43%) and 13 responses in paper format (18.57%).

Fig. 1: Distribution of the surveyed workplace mentors by their current position



Our sample is composed of 12.86 % female and 87.14 % male mentors of apprentice engineering students. As shown in Fig. 1, we observed that the highest participation was by technical experts, who composed 34.29% of our sample. A majority of the mentors (60.00%) surveyed in our sample have considerable professional experience of between 10-25 years, as indicated in Fig. 2 below. It is interesting to notice that almost a quarter of them (22.86%) have more than 25 years of professional experience, being mostly at the end of their career.

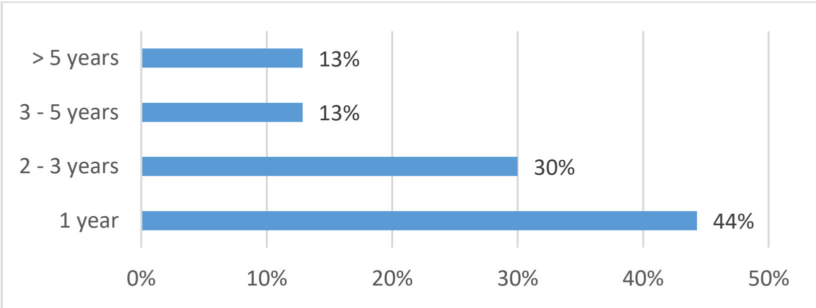
Fig. 2: Distribution of the surveyed workplace mentors by their professional experience



Concerning the surveyed mentors' experience in mentoring engineering degree apprentice students, our sample is composed of mainly experienced mentors

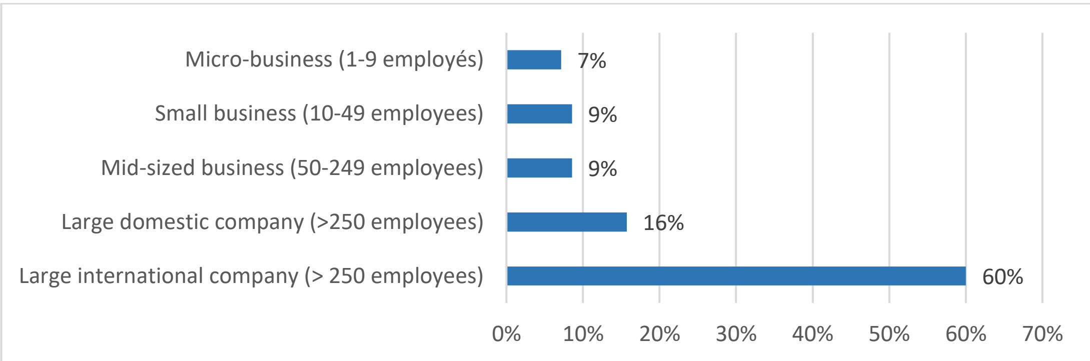
(55.71%). As illustrated in Fig. 3, more than quarter of them (25.71%) have mentored three or more engineering students during their professional career, indicating a significant level of motivation and experience in workplace training.

Fig. 3: Distribution of the surveyed workplace mentors by their mentoring experience



Regarding the surveyed mentors' organisations, three quarters of the surveyed mentors (75.71%) are employed in either large domestic companies (15.71%), or mainly international (60.00%) industrial companies, with more than 250 employees (See Fig. 3). We can observe a relatively small proportion of surveyed mentors who are from medium-sized (8.57%) and small (8.57%) industrial companies.

Fig. 4: Distribution of the surveyed employers by their organisation size

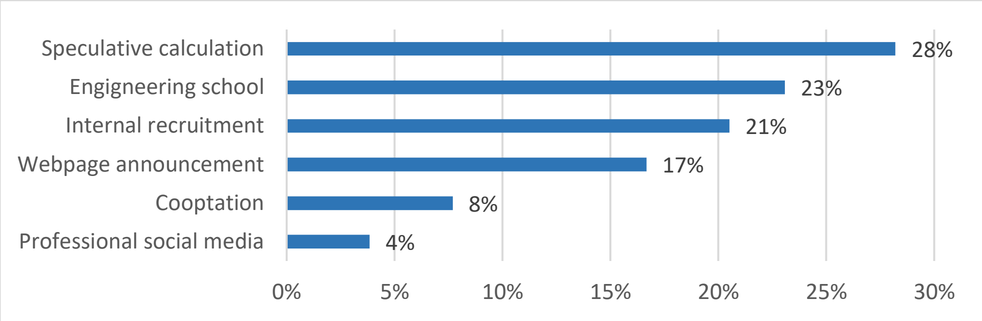


In our initial research design, we had planned to complete advanced statistical analyses on collected data. Finally, we opted to analyse our data with descriptive statistical analyses because of our limited sample size (n=70) in this preliminary study.

RESULTS AND DISCUSSION

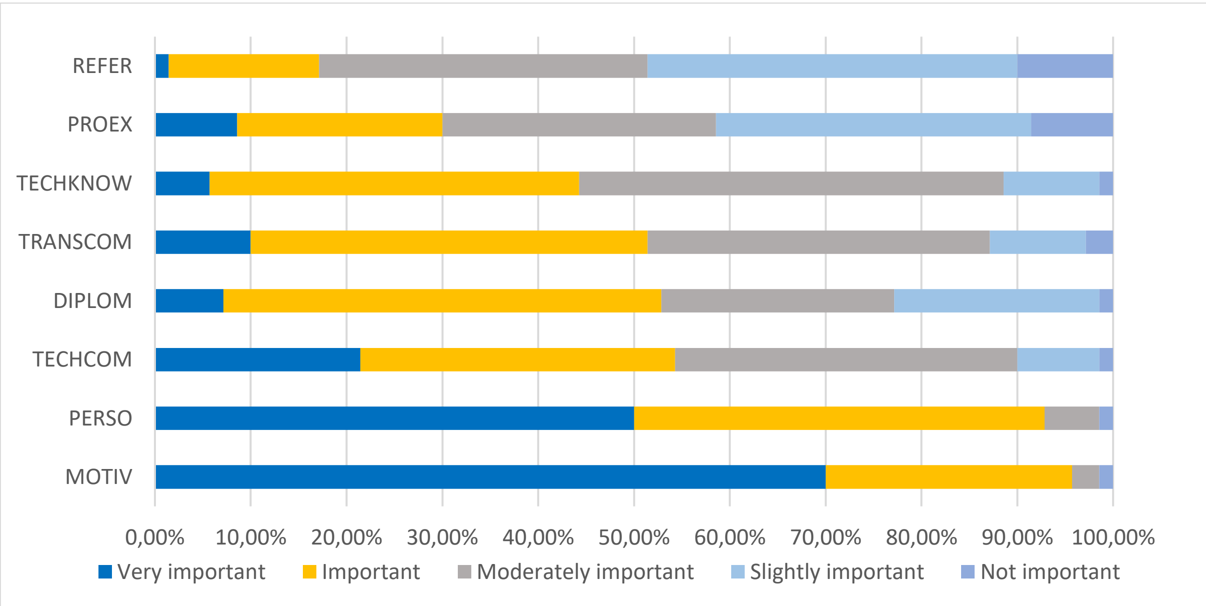
To answer our first research question (RQ1), we investigated workplace mentors asking how they recruited their engineering apprentices. Our results indicate (Cf. Fig. 5) that most of the engineering apprentices were recruited on the basis of students' speculative applications (28.21%) or via their engineering schools (23.08%), something that didn't confirm the results of previous studies (Fabian et al. 2023, Drewery et al. 2022). The recruitment via engineering schools indicates a closer relationship between engineering schools and certain industrial companies, as well as a potential coordination between the academic and corporate recruitment process. As expected, internal recruitment (20.51%) is an important recruitment tool that could be considered as an opportunity for future promotion. The fourth significant engineering apprenticeship recruitment source is via job advertisements posted on official websites (16.67%). Surprisingly, professional social media (such as LinkedIn) are used relatively sparingly (3.85%).

Fig. 5: Recruitment sources of engineering apprentices



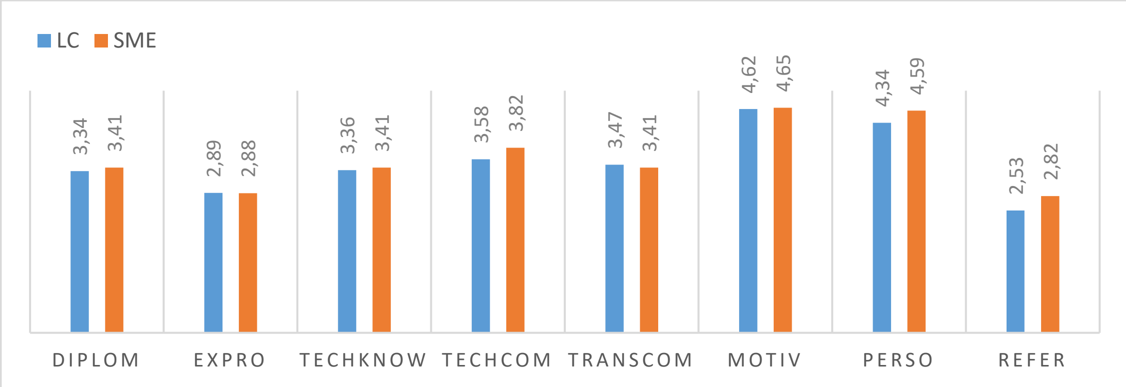
Our results concerning the selection criteria and standards (RQ2), in line with the previous results of Ruiz and Goastellec (2016), highlight a very strong importance given to students' motivation (MOTIV = 92.00%) and personality (PERSO= 86.86%) as illustrated in Fig. 6. Significantly lower importance (on average around 63%) was given to their technical (TECHKNOW) and theoretical competences (TECHCOM), professional experience (EXPRO), graduate diploma (DIPLOM), or transversal competences (TRANSCOM). This could indicate an awareness and recognition by mentors of the quality of the academic selection that engineering apprentices have undergone prior to their workplace recruitment process. At present, the academic and workplace recruitment processes are separate and without any official link. However, engineering apprentice students looking for their placement after the validation of the academic recruitment process could be an indicator of a high level of their technical, theoretical and transversal competences.

Fig. 6: Recruitment criteria of engineering apprentices



Regarding the influence of organisational characteristics on the mentors' recruitment decisions (RQ3), our findings didn't confirm the results of Protsch (2017) as we observed only relatively slight differences between large national and international industrial organisations and SME's.

Fig. 7: Recruitment criteria of engineering apprentices by organisational types



Workplace mentors' in large domestic and international industrial companies put less emphasis on references (-6%), personality (-5%) and technical competences (-5%). Between experienced and inexperienced mentors there are only relatively slight significant differences concerning motivation, as experienced mentors gave somewhat more weight to candidates' motivations (+3%). Surprisingly, mentors with more than 10 years of professional experiences gave more weight to theoretical knowledge (+ 6.8%) and references (+6%) and less to professional experience (-6%).

CONCLUSION

In this study we investigated industrial recruitment practices and standards for hiring engineering degree apprentices. Contrary to our expectations, our results indicate a relatively weak role of professional social media and co-optation in the recruitment process. A majority of engineering apprentices are recruited via students' speculative applications and with the help of their engineering schools. For industrial companies, the two most relevant recruitment criteria for their apprentice selection procedures are students' motivation and personality, with the other criteria lagging far behind. Surprisingly, we did not find significant differences between large and small industrial companies, or between experienced and inexperienced apprentice mentors in their recruitment decisions.

The evidence from this study suggests the need for more collaboration between engineering schools and industrial organisations in recruitment processes for degree apprenticeship engineering students (for example, with greater participation of representatives of industry in the academic recruitment process - allowing students to choose their degree apprenticeship partnerships at this early stage). Currently, the academic and workplace recruitment processes are quite separate, with only relatively limited formal connections between them. After the validation of the academic recruitment (conditional admission in their engineering school), students are left alone to find their workplace with a relatively tight deadline to meet. However, family support and students' social origin are key determinants of students' success, and these factors generate significant inequalities in the selection process (Kergoat 2022). Consequently, workplace apprentice selection is significantly influenced by students' social status via their cultural and social capital. This is more particularly true in the French engineering education context, where the engineering profession has historically enjoyed a high social status and prestige. Also, engineering studies are mainly considered as a privilege reserved for the most gifted students with outstanding academic results, implying a complex and highly selective recruitment process (Gille et al. 2022). This persistent reputation related to an image of excellence (Moulignier et al. 2019) could discourage talented students from lower social backgrounds from applying for degree apprenticeships in engineering schools. To develop a more balanced recruitment process, it would be valuable to propose an individualised support framework for all students from lower social origins, right from the start of the degree apprenticeship selection process, based on a close collaboration between industry and academia. This would not only make the entire recruitment process more inclusive, thus attracting a more diverse student population, but also could facilitate the influx of new talent in French engineering education.

We are aware of the most important limitation of our study, namely that our findings are based on a limited number of responses - precluding the generalisation of our results. Also, we have investigated workplace mentors of engineering degree apprentices in only one French engineering school and in a limited number of apprenticeship programmes that cannot be considered as representative of degree apprenticeship mentors at a national level.

To further our research, we intend to extend our investigations with the aim of obtaining a higher number of responses, thus allowing us to carry out advanced statistical analyses on our results. Also, it would be interesting to investigate apprenticeship mentors from engineering schools not only at the national, but also at the European level. Finally, we plan to complete our quantitative study with a qualitative study to allow a better understanding of our degree apprenticeship mentors' perceptions, as well as students' perceptions, of their recruitment processes.

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SELF-ASSESSMENT OR PEER ASSESSMENT? WHICH IS BETTER PREDICTOR OF TEST RESULTS

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Keywords: *self-assessment, peer assessment*

ABSTRACT

Internationally accredited engineering programmes are becoming increasingly important in the internationalisation agenda of universities. ABET has highlighted transversal skills in its accreditation criteria for engineering degrees. Preferred transferable skills include the ability of students to reflect on their own performance, the ability to give constructive feedback and the ability to make judgements.

Students' self- and peer-assessment was examined in the context of a basic mathematics course. During the maths midterm tests, students self-assessed on each task, and assessed another student's test. These assessments were compared with the points given by the teacher. 84% of students overestimated their actual performance and more than 60% of them overestimated their peer's performance, and both overestimations were low. According to students' opinion, peer assessment is as easy as self-assessment, it is not easier for them to spot mistakes in other people's work than in their own. The research results showed significant difference in the accuracy of peer and self-assessment, peer assessment is closer to teacher evaluation than self-assessment. Contrary to our previous research, now we did not find a significant correlation between students' performance and assessment accuracy in the first test. One reason for this may be that these students have failed this subject at least once.

As further learning is only possible once we have identified what needs to be learned, the ability to assess the gained knowledge as accurately as possible is appreciating. In addition to meeting accreditation requirements, the different type of assessments' cognitive and affective effects on learning outcomes make it a good choice for classroom use.

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1 INTRODUCTION

In the last decade, the rapid development of engineering industry and the acceleration of robotisation have had an impact on employment. Although education is a slowly changing system, it has to respond to these changes. In addition to technical knowledge, transversal skills have become increasingly valued and are being developed with increasing emphasis by higher education institutions. International accreditation requirements also address the development of these competences. There is a huge literature on the study of transversal skills, but there is no single agreed definition between academic and non-academic organisations, which makes it difficult to measure [1]. Despite the diversity of the list of transversal skills, the ability to self- and peer-assess is one of them [2].

Because learning is more than simply acquiring knowledge, it involves students' active participation in judging their own work and proactively seeking and using inputs from others. Self-assessment (SA) and peer assessment (PA) require students to take an active and reflective role, to understand and apply assessment criteria, to seek and use feedback and to evaluate their own and others' work [3]

1.1 Self-assessment

First, it is important to clarify that self-assessment is an umbrella term that encompasses a range of self assessment. Panadero et al. [4] identified 20 categories of SA implementations, varying from a simple form of awarding a grade for their own work (i.e., self-grading or self-marking) to a more complex form that evaluate their own work based on predetermined criteria, capturing the strengths and weaknesses of their own work.

1.2 Peer assessment

Secondly, peer assessment, like self-assessment, is also an umbrella concept that encompasses a range of peer assessment. Van Helden et al. [5] distinguished three types of PA according to their function in educational output.

1. Peer review: students review each other's (written) output and give feedback to each other. The recipient of the feedback is not obliged to reply to the feedback and change their output based on the feedback. Examples of outputs : essays, reports, computer code.
2. Peer grading: students grade each other's work in a formative or summative way based on a pre-defined set of criteria. It is not a detailed feedback, rather it is limited to the answer is correct or to what extent the student has delivered what was asked based on the given criteria.
3. Peer evaluation: students evaluate each other during the learning process and reflect on for instance transversal skills within this process.

Different peer assessment methods are used depending on the content of the subjects and the skills developed by the subject. In mathematics education, peer review and peer grading is the most common form. Pick et al. [6] used self assessment and peer review in a matematics course for first year engineering students. Students assessed each other on 4 criteria and they had to reflect weekly on comments received from peers:

1. Effort (Clear evidence of effort in answering - even if not correct)
2. Correctness (All correct)
3. Coherence (Method can be followed very clearly (even if answer not correct). Excellent annotation, notation and clear steps)
4. Conciseness (Method used is appropriate and very efficient)

This research is a good example of the many ways in which maths performance can and should be assessed. Until now, mathematics education has focused primarily on solving problems correctly and evaluating only this.

1.3 Objective

In a previous study I examined the accuracy of self-assesment of engineering students, some relationships between self-assesment and performance, and the impact of feedback on self-assesment [7]. In addition to self-assessment, peer assessment also plays a role in this research. Therefore, the present study aimed to answer the following questions:

1. To what extent are engineering students overestimating and underestimating their performance and their peer's performance in a basic mathematics course?
2. Is there a significant interrelationship among accuracy scores and performance?
3. Is there a significant difference in the accuracy of self-assessment/peer assessment between students who fulfilled mid-term requirements and those who did not?
4. Is peer or self-assessment closer to teacher assessment?
5. How easy do students find it to evaluate their own and others' work?

2 METHODOLOGY

2.1 Measure of self-assesment

Several indices of self-assessment can be distinguished, e.g. the accuracy (reliability) and the direction of the bias (validity). Based on the literature [8] the accuracy and direction of students' self-assessment was measured using two indicators: the realism/bias score and the accuracy score.

Realism/bias score = (Average self-assesment score over all items in the test) – (Average performance score over all items in the test)

Accuracy score = the absolute value of the difference between the self-assesment score and performance score for each test item, summed over all items on a test, and divided by the total number of items

During the semester, students wrote two midterm tests and an exam. To take the exam, students must achive a score of 50% in the two tests together. Those who did not meet this requirement could take a make-up test. Each test consisted of 6 tasks for 2 points per task. Before tests, students were given the opportunity (extra lessons) to take more mock tests and learn the scoring rules for each task. Students graded each task scoring 0, 1 or 2 points. Teacher assessment could also be 0, 1 or 2 points.

Based on this, the bias value could take a value between -2 and 2, where a positive value indicates that the student overestimated his performance, while a negative value indicates underestimation. Values close to 0 indicate a lack of bias. The accuracy score could take a value between 0 and 2, where 0 indicates complete accuracy and 2 indicates complete inaccuracy.

2.2 Participants

142 engineering students took the course Mathematics 2, 124 students wrote the first midterm test, 99 the second midterm test. All students have registered for the course at least once, but have not fulfilled the basic requirements of the course.

3 RESULTS

Self- and peer-realism scores were calculated from the results of self- and peer-assessment following the midterm tests and from the teacher’s assessment. 84% of students overestimated their actual performance in both midterms. Peers scored the tests more critically, 79% of them overestimated the other's performance on the first test and 67% of them on the second (Table 1).

Table 1. Distribution of self- and peer-realism scores

	Self-realism score midterm test1			Self-realism score midterm test2			Peer-realism score midterm test1			Peer-realism score midterm test2		
	<0	0	>0	<0	0	>0	<0	0	>0	<0	0	>0
Number of students	7	11	95	7	5	62	11	13	92	10	14	49

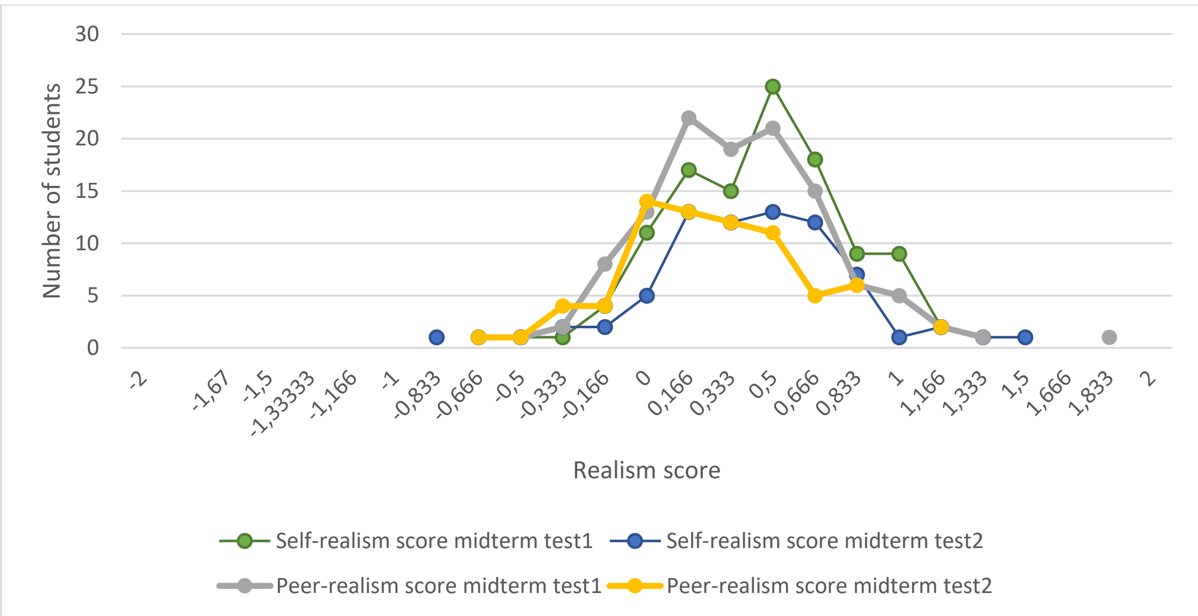

Fig. 1. Realism scores in the tests

In the interval 0-0.5 we talk about low overestimation, between 0.5-1 moderate overestimation, between 1-1.5 high overestimation, between 1.5-2 very high overestimation. Peer assessment is closer to teacher assessment than self-assessment, namely peer assessment shows lower overestimation than self-assessment (Self-realism score1: mean 0.43, Self-realism score2: mean 0.42, Peer-realism score1: mean 0.37, Peer-realism score2: mean 0.27) (Fig 1).

When comparing peer and self-assessment, it can be seen that peer assessment is closer to teacher's assessment than self-assessment in both tests. Using a paired samples t-test, this difference is significant (Table 2). Thus, it can be said that students score their peers' tests more strictly than their own, they notice errors in their peers' tests more easily. One reason for this may be that it is easier for students to check the sub-steps of an existing thought process than to create and construct a new one.

Table 2. Paired samples test between self- and peer-realism scores

		N	Mean	SD	Sig.
Realism score midterm test1	Self-realism score	110	0,432	0,356	0,040
	Peer-realism score	110	0,368	0,374	
Realism score midterm test2	Self-realism score	72	0,421	0,4	0,000
	Peer-realism score	72	0,271	0,364	

Accuracy scores were used to find correlation between self-assessment accuracy and test results. The results of the correlation calculation are shown in Table 3, which does not show correlation between the accuracy scores and the first test scores. In contrast, for the second test we found a negative correlation between the accuracy scores and the test scores. Negative correlation means that students with better results in tests have an accuracy score close to 0, i.e. they give a more accurate self-assessment of their own performance than students with weaker results.

Table 3. Correlation between accuracy scores and test scores

	Accuracy score midterm test1	Accuracy score midterm test2
Midterm test1 score	-0,078	
Midterm test2 score		-0,383**
Total score of tests	0,29	-0,297*

*p<0,05 **p<0,01

In a previous research [6], there was a significant correlation between test scores and accuracy score for both tests, which is partly in contrast to the current results. One reason for this may be that while in the previous research students took the subject for the first time, in the current research students took it for at least the second time which means underperforming students were only in the sample.

An influencing factor behind the change in the significance of the correlation in the current study may be that those students did not come to take the second test who had little chance of completing the subject based on their poor first result. 25 fewer students wrote the second test, and 19 of them got 4 or less scores on the first test.

If students' self-assessment is further examined in terms of their performance, then while there is no significant difference between students' accuracy scores who meet the requirements of the subject and those who do not in the first mid-term, there is a significant differencs in the second (Table 4). Thus, the accuracy scores of students who finally fulfilled the requirements of the course improved significantly compared to students who did not complete the course requirements.

Table 4. Difference between accuracy scores based on the fulfillment of requirements

		N	Mean	SD	Sig.
Accuracy score midterm test1	Not fulfilled the requirements	59	0,590	0,331	0,667
	Fulfilled the requirements	56	0,565	0,285	
Accuracy score midterm test2	Not fulfilled the requirements	27	0,716	0,351	0,01
	Fulfilled the requirements	46	0,514	0,216	

3.1 Students feedback about self and peer assessment

Students were asked how easy it was to assess their own work and others. They rated the difficulty of self- and peer-assessment on a 5-point Likert scale. Students found self-assessment and peer assessment almost equally easy (mean of self-assessment 2.69, mean of peer assessment 2.80).

"Evaluating our own work is difficult because it is difficult not to be biased against ourselves. However, evaluating a student's work can be easier because we can discover solutions that we hadn't thought of, or we can be reassured that he or she has carried out the task in the same way and that his or her results are the same as ours. "

"It's very difficult to evaluate until there is only one answer for another subject, there are many steps here everyone thinks differently. But after some practice I could assess with more confidence. "

"I think that as difficult and sensitive as the topic is, it is also useful because we can see and learn from the solutions of our fellow students. "

4 CONCLUSIONS

Overall, the data suggest that the accuracy of self-assessment varies significantly during the semester, especially for students who meet the requirements of the subject. Factors that may affect the improvement in self-assessment accuracy include checking the mistakes in the first test, practicing and scoring the mock tests, and practicing with midterm quizzes. Accuracy of peer assessment showed a significant difference from self-assessment, even though students perceive self-assessment and peer assessment to be equally easy. The students' evaluation is closer to the teacher's when it comes to evaluating their peers' work than their own.

As engineers work in teams, they need to evaluate their own work and understand and evaluate the work of others as well. Therefore, the development of these competences should also be emphasised during their university studies.

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Development and evaluation of a teaching concept that focuses on increasing modeling competence in Technical Mechanics (TM)

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ABSTRACT

Engineering students often learn by retracing pre-calculated given solutions of tasks and try to understand this problem-solving way. This reconstruction is not always successful in solving new types of problem via modified tasks (Rossow 2008).
Every mechanical exercise follows the same solution methodology (Müller-Slany 2018). Applying this basic problem-solving structure correctly is a Pre-condition for solution's reflection and is therefore essential for teaching. To improve these competencies a strategy training is implemented in exercise-settings in Technical Mechanics (TM).
By solving in separated model steps pre-structured exercises with differences in depth of structure and always visualizing these steps, the awareness and applying of

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each step should be increased. This research approach aims to investigate the effects of explicit strategy training on the problem-solving skills of engineering students in TM in an experimental design. Research Questions are: what influence does the strategy training have on the knowledge and recognition of the model? What influence does this training have on correct application of this methodology? What influence does this application have on the correct solution of tasks?
As part of a quantitative analysis a self-constructed test for measuring the modeling recognition in Multiple Choice format as well as a competence test to evaluate the application of the problem-solving model were implemented and tested. First results of the research design and the intervention itself are presented.

1 INTRODUCTION

1.1 Background

For engineers it is important to solve problems in a structured way (cf. Lehmann 2008), so good problem-solving skills are a basic for successful engineering work. In engineering study courses, the lectures of the first two semesters are often oriented on basic knowledge and training of mathematical skills, but there is less teaching time for supporting transfer knowledge in the field of technical mechanics (cf. Müller-Slany 2018).

The processing of problems in form of tasks is of central importance in Technical Mechanics (TM). They are used for learning in the form of exercises, but also serve as examination tasks to evaluate students' competencies. For students in TM it is often difficult to work on exercises: they rarely find the approach and/or fail at the mathematical implementation to solving the tasks (Brandenburger 2014). During the exercise, students often try to learn mechanical knowledge by retracing pre-calculated given solutions of tasks (cf. Rossow 2008). But with this learning approach students often do not recognize the based solution methodology and so cannot transfer this problem-solving model to new, unknown tasks. High failure rates in mechanical exams often are a consequence of a lack of transfer knowledge (Rossow 2008). This limited technical problem-solving ability leads to bad exam results.

In TM all tasks can be solved through the same solution methodology. To improve the ability for applying transfer knowledge and so achieving an improvement of students learning outcomes by solving new tasks of various contexts correctly, the awareness and application of the correct (single) solution method must be practiced in teaching visibly and actively.

1.2 Problem-solving Process

In Germany teaching is often structured by problems that are mainly presented in the form of exercises and with these exercises the learners' performance can be classified (cf. DAAD German Academic Exchange Service 2023).

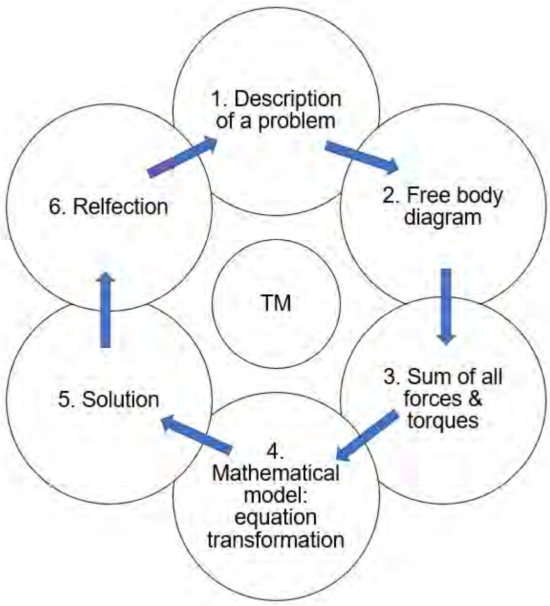

Fig. 1. Solution Methodology of TM tasks (cf. Müller-Slany 2018)

For understanding the way of problem-solving in detail to solve tasks with unknown contexts in TM its necessary to use an efficient focused strategy.
This strategy consists of a structured solution methodology that focuses on a knowledge-based approach (cf. Friege 2001). The basis is the always the same systematic structure of the solution path of mechanical tasks (cf. Müller-Slany 2018) illustrated in figure 1.
By applying this general model to TM, the following steps of solution methodology result: The problem will be represented by visualizing the free body diagram with all relevant variables (e.g., forces and torques) in the given system. In addition, assumptions are made to simplify the following calculation.
The sum of all forces and torques are established and transformed into an equation. The solution is developed by resorting to factual knowledge (e.g., $\sum F_i = 0$) and relationships between knowledge elements (e.g., forces can be summarized to one resultant force with the same effect on the system).
A mathematical model is defined for calculating the unknown variables. A formula for solving the unknown variables is given by a relation between the known variables. A solution is worked out by a solution path (e.g., equivalent transformation of an equation).
After a solution has been determined, its correctness and meaning in relation to the task context have to be evaluated. A more detailed examination shows that the phases of problem solving vary in difficulty. Solving and understanding a problem is often easier than creating a representation and working out a solution. This is shown in research results on problem solving (Chi et al. 1981). It is mentioned that the representation and development of a solution (steps 1 to 3 according to Müller-Slany) are basically to find the solution of a problem. The solution of the searched variable is then just a correctly typed sequence of values in the calculator and a logical consequence after the correctly applied solution way. (cf. Heller et al. 1984).

2 METHODOLOGY

2.1 Intervention

Due to the unsatisfactory results of the students in the problem-solving process for mechanical tasks, a new teaching concept is developed and implemented in a mechanical engineering course. It should promote problem-solving skills of engineering students to solve TM problems. For this, a strategy training is used that should improve the reflection process of the methodological proceeding on the one hand and the evaluation of the solution itself on the other hand. In the strategy training (pre-)structured learning tasks are provided to varying degrees. The initially specified and visualized structure and the systematically dissolving of this to the end of the semester should increase the internalization of the schema. As a consequence, students should be able to apply the schema correct (cf. Beland 2017). Each exercise is divided into subtasks inspired by the modeling cycle and visualized as an Advance Organizer. After applying the model to a (solution of a) task of high complexity through the teacher, the next tasks' solutions have to be worked out by the students themselves to encourage the learning activity (Atkinson et al. 2003).
Students are guided through each problem-solving step, which is defined in detail in form of subtasks. The whole solution path is following this guidance for solving

prototypical, partially contextualised learning tasks. The following figure shows the schedule of the strategy training implemented in an exercise course.

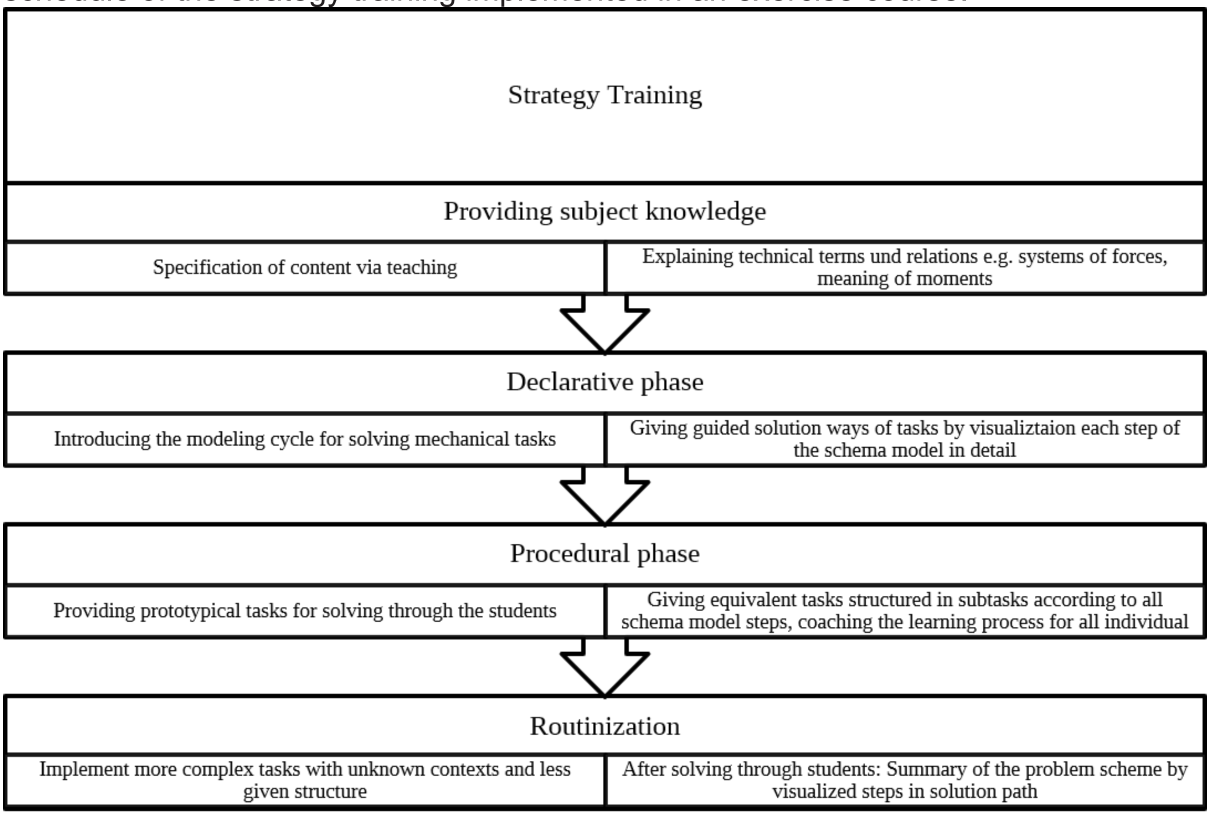

Fig. 2. Schedule of strategy training

At the beginning of the exercise the teacher gives an overview of the topic, shows a worked example of high complexity with (all) visualized modelling steps in the solution path. During the exercise students work on their learning material on their own and could ask subject related questions, but there are no instructions that influence the problem-solving process. They have the opportunity to get coaching individually during their problem solving but the teacher is not giving solutions, just prompts. This framework leads to an active participation of the students.

The problem-solving scheme in all subjects (systems of forces, equilibrium systems, stress resultants and trusses) is the same so that the strategy training is performed equally for each subject. As the number of semester weeks increases, the complexity of the tasks automatically increases, since more relations are used and the modeling cycle for a task is repeated several times when the topics are expanded over the semester. There are more systems for describing all variables and as a consequence the complexity of the solution path increases. Because of this the scaffolding approach is implemented just at the end of the semester.

2.2 Method

With this research study the effect of the used strategy training on problem solving skills of mechanical engineering students in statics will be investigated. For measuring these effects two self-designed tests for evaluation the schema recognition and the schema application are implemented.

As a longitude study the tests are used in a pre-post design: at the beginning and end of the semester to comprehend a base between the two groups and to compare later results to this condition for measuring the learning increase.
The influence of the strategy training could be evaluated with a direct comparison in a 2x1- design. There are two different exercise groups: one with the implemented intervention and one with a regular teaching format for exercise courses. The intervention is implemented in a mechanical exercise related to the ongoing lecture. For data evaluation, both tests are evaluated using the Rasch model that describes the students' performance. Subsequently group comparisons will be made that provide results for the success in problem solving of TM tasks.

2.3 Research Questions

To assess the effect of strategy training on problem solving in engineering mechanics, the following research questions need to be addressed:
(Research Question 1) What influence does the strategy training have on student's declarative knowledge of schema steps? (Hypothesis 1) Due to a permanent visualization and repetition of the schema steps in each task, the knowledge about the existence of the steps and the corresponding content elements is highly expected due to the recognition effect.
(Research Question 2) What effect does the strategy training have on student's procedural knowledge of the schema? (Hypothesis 2) Because of the continuous visual assignment of the schematic steps in the solution path of each task, the knowledge of the processed steps and the corresponding (mathematical) actions is also highly expected.
(Research Question 3) What influence does the exercise concept have on the technically correct application of the schema to new, unknown tasks? (Hypothesis 3) It is assumed that the always same predefined solution structure in the form of subtasks, which are based on the modeling cycle, is internalized in such a way that these steps can also be applied correctly to new tasks independently.
(Research Question 4) What is the relation between the correct application of the schema and the correct end result of the task? H4: If all schema steps are applied completely, a high correlation is expected between a high solution rate of the schema application and the correct final result of the unknown variable of the task.

2.4 Test Instruments

The influence of the strategy training on the schema recognition and application will be evaluated by using a self-designed schema recognition Moodle test in a multiple-choice format as well as a problem-solving test for mechanical tasks (on exam level).

2.4.1 Schema recognition test

This Moodle test is divided into two parts. There are some questions to evaluate the declarative schema knowledge and another part for measuring the schema recognition to procedural knowledge. The first part based on describing the steps in the modelling cycle, so the students have to determine the content elements of each step and put the steps in the correct order. Also, they have to assign steps to given solution parts (8 items in total).
In the procedural part of the test the students have to recognize the (in task named) steps in precalculated solutions of tasks that differ in the number of solution steps that have already been calculated (Fig.3). This procedure is applied to all four

subjects and for each precalculated step so there are 20 Items in total for this assignment.

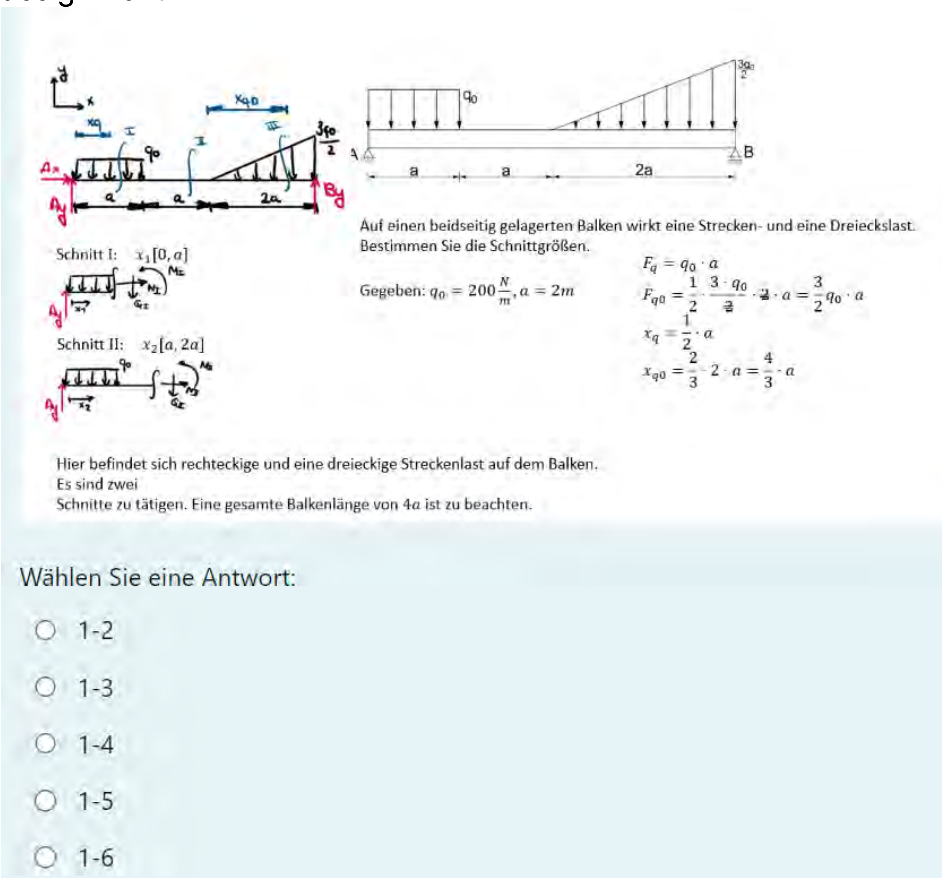

Fig. 3. Part-Screenshot schema recognition test: procedural knowledge (german version)

2.4.2 Schema application test

The competence test was implemented last semester as a paper pencil test with tasks of open format. To give an overview of the test format, there is given one example of task of the actual problem-solving test in the following figure.

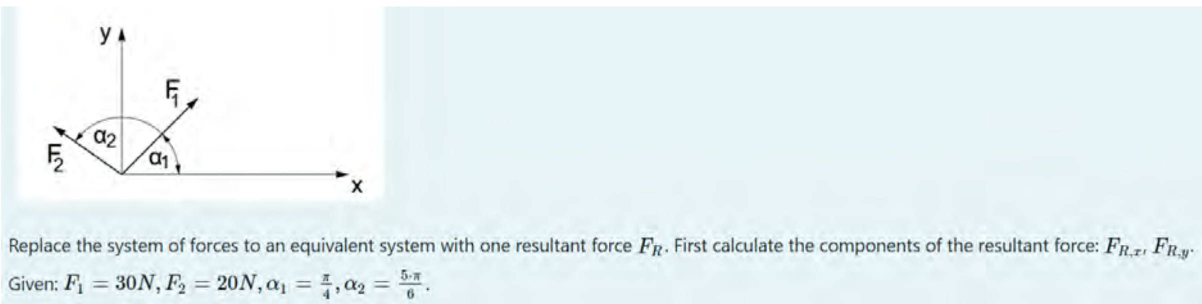

Fig. 4. Example of task of schema application test

Here both forces have to be resolved in their components with a drawing and calculation that is named the free body diagram and then the sum of forces in both coordinate directions must be deployed (= sum of forces). After setting up the sums of each coordinate axis the components can be calculated (=formula) and via Pythagoras added up to the resultant force (= solution). In the last step the result has to be reflected (= evaluation) in the context of the task.

3 PRELIMARY RESULTS

The first implementation of the described intervention was piloted in the winter semester 2022/2023 via an experimental-control-group design in an exercise course of business engineering students in statics with a sample size of 90 students in total at the beginning of the semester. This size decreases during the semester to a size of 70. Only 15 students regularly participated in the strategy training. The exercise was a voluntary offer and thus, the number of students who participated in the study was too small. Due to this, no group comparisons could be made.The number of students that have done the tests completely was about 70. The schema recognition test was implemented via Moodle and the competence test via paper-pencil format. Then both tests were evaluated via Rasch analysis.

Results of the tests instruments are that the schema recognition test divided into declarative and procedural knowledge are too easy because of the lack of relation to mechanical subjects. Due to the smaller number of items that measure declarative knowledge a separated evaluation of declarative and procedural schema knowledge is not possible.

The following table shows the values of the average discrimination (DIS) and person (R_P) as well as item reliability (R_I) according to Cronbach's Alpha of each schema recognition test at the three measurements (pre, midterm and post).

Table 1. Results of schema recognition tests

	Pre	Midterm	Post
DIS	0.25	0.35	0.38
R_P	0.654	0.451	0.583
R_I	0.621	0.725	0.774

The results show that the reliability values over 0.5 are acceptable so the tests are valid for measuring person ability with these items. The reliability of items increases over the test period. The values of discrimination are under the strong limit of 0.5. Due to insufficient discriminatory power, an item was removed from the test. In this item a step was to be assigned a name, but it was not clear whether it should be just a word or a description. Even if the task was changed, the one word for the last step of the schema (reflection) would not be difficult to find, so the item was removed. Another item was removed from the test because it was the only one that consists of another structure (with answer sentence to differ between reflection and answer sentence) and the result was a poor resolution rate. Then a mean discriminatory power of 0.45 could subsequently be achieved. All items of declarative knowledge were solved with over 90% so the test was too easy because of the lack of reference on subject. The solution quote in the procedural part was solved with an average solution quote of 70%. The test is also quite easy and differences less in complexity. Here the test will be modified by giving the precalculated solution steps not in an extremely structured arrangement as given actually. The analysis to Rasch (dichotomous model) shows the following distribution of item difficulty and person ability via Wright Map for the schema recognition test at post measurement: Here the low complexity of the test is confirmed. The person ability spreads round zero, the item difficulty spreads round – 1,89 (same logit-scale).

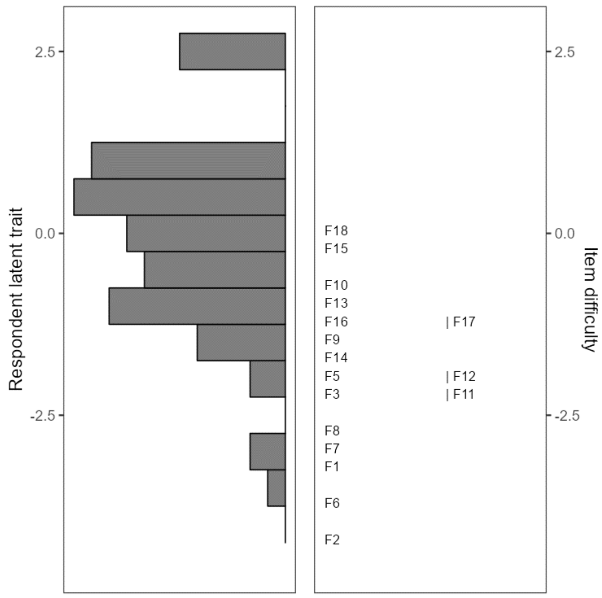

Fig. 5. Wright Map Schema recognition test post

The shift of the distribution shows that the item difficulty is significantly lower than the person ability and that the test is therefore too easy. The competence test was evaluated via code manual and measured a quote of correct schema application (of each step of the modeling cycle). First results show that the tasks differentiate well in complexity and person ability. Because of just five tasks in total an evaluation according to item-response theory is not possible. The setting of this test has to be modified for the main study.

4 SUMMARY

The way of problem solving is essential for understanding and solving technical mechanical tasks, which students try to understand by retracing the solution path. The outlining of the problem-solving strategy is missing. To improve those skills a strategy training is used, that combines worked-examples and the schema application through the students by giving pre-structured tasks according to each step of the modelling cycle and always visualize them. Moodle tests for measuring the influence of the strategy training on schema recognition and application were tested. The declarative knowledge part of the schema recognition test will be adjusted to questions that evaluate knowledge about the modelling steps more related to the subject mechanics. The competence test showed a good selection of tasks that vary in difficulty, but the number of tasks was too small for an evaluation. More tasks in the test means another format for this test because of test economy. The open tasks could not be used for this, instead the individual problem-solving steps must be solved independently via Moodle.

The intervention and test instruments will be implemented to mechanical engineering students of the first semester, the sample size is approx. 100 students. In order to ensure full participation in the study, the processing of the tests is set as an admission to the exam. The strategy training requires attendance. Covariates for this study are: Gender, age, grade of mathematics, grade of physics, repeater of the course, semester, university entrance qualification, prior subject knowledge TM, finale grade, interest in TM.

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COMMUNITY-BUILDING AMONG PHD STUDENTS IN ENGINEERING EDUCATION RESEARCH: THE SEFI SUMMER SCHOOL AND AAEE WINTER SCHOOL

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ABSTRACT

Engineering Education Research (EER) is a rapidly evolving and increasingly valued research field. This supports the number of PhD students to grow steadily, but unfortunately, they are often limited to a few within the large engineering faculty/department, having different backgrounds and interests. Additionally, the

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research methodologies needed by EER researchers are usually different from the classical technical engineering research (TER) methodologies. This translates into a need for specific training and opportunities to get to know each other better in order to promote international collaboration and develop a community of practice. SEFI and the Australasian Association for Engineering Education (AAEE) both organized a summer/winter school for EER PhD students in 2022, attended by 34/14 participants respectively (note: attendance at the AAEE winter school is not limited to PhD students). We have designed a survey to elicit a mixture of background information (facts), perception data (opinions), and evaluative data (evaluation of the school).

By using confirmatory factor analysis on half of the items and descriptive statistical analysis of all data, we aim to provide insights into the success factors of these schools. Both schools attracted a diverse group of EER-PhD students in different areas. The SEFI summer school excelled in building an inclusive and international research community, whereas the AAEE winter school was superior in gaining domain-specific knowledge needed for EER research. The results contribute to a more nuanced understanding of the issues experienced by researchers who are beginning their career in EER and support organizers in designing international research schools.

1 INTRODUCTION

1.1 Engineering Education Research

Engineering Education Research (EER) is continuously growing as an internationally connected field of inquiry (Godfrey and Hadgraft 2009; Borrego and Bernhard 2011; Bernhard 2018), strongly intertwined with general Higher Education research (Henderson et al. 2017). EER is one of the many research fields (such as CER (computing education research), sitting at the intersection of a STEM discipline and education research, called ‘discipline-based education research (DBER)’, one not ascendant over the other but rather equal in contribution and outlook (see Fig.1.).

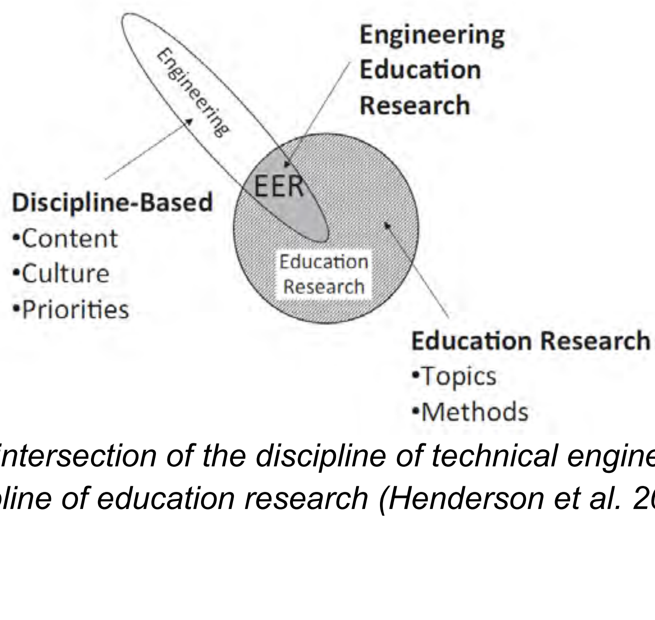

Fig. 1. EER at the intersection of the discipline of technical engineering research and the discipline of education research (Henderson et al. 2017, 349).

The importance of porous boundaries between EER and other relevant academic disciplines has been highlighted by Klassen and Case (2022). EER is by consequence an interdisciplinary research field, resulting in specific opportunities and challenges, but it also has specific needs and stumbling blocks because of its emerging nature (Baillie, Ko, Newsetter and Radcliffe 2011; Edström, Kolmos, Malmi, Bernhard and Andersson 2016).

In summary, we can say that the community of EER-PhD students is heterogeneous with various paths into the field (engineering, social sciences, educational sciences, psychological sciences, etc.) and different working conditions. Often EER-PhD students work isolated from other PhD students in EER and have a unique profile within their local institutional group of PhD students in technical engineering research (TER). So, it is no surprise that Kristina Edström and colleagues (2018) wrote: “In order to learn from the complementary perspectives, it will be necessary to support dialogue and collaboration between researchers.” and “unless there is an arena where interaction within EER can be accommodated, there will be no identity as EER researchers, and no sense of belonging in a joint endeavour”.

1.2 Summer/Winter Schools in Engineering Education Research

Doctoral training is often performed in structured programmes operated by individual universities. However, few formal programmes exist for the training of EER-PhD students (Borrego and Bernhard 2011). This makes sense given their small numbers in the universities concerned. However, formal training programs are important not only for community building and generating the feeling of belonging but also due to the fact that many researchers starting their EER journey are making a transition from a technical engineering discipline to engineering education research (Dart et al. 2019).

A logical solution is to organize this much-needed training during an international residential summer or winter school which fully immerses the participants into the subject and supports community building. AAEE has a long tradition (since 2011) in organizing such winter schools for EER-PhD students (https://aaee.net.au/winter-summer-school/). The topics are diverse (research methodologies, partnerships, grant opportunities, etc.) and are facilitated by experienced Australasian researchers in the field of engineering education who have undertaken different paths in their transition to EER (Wiley et al. 2022). SEFI organized in 2022 the first summer school for EER-PhD students with a focus on research methodologies and community building, supported by a diverse group of experts not only in EER, but also in statistics, education and psychology (https://www.sefi.be/wp-content/uploads/2021/12/programme-SEFI-Summer-School_2022-v3.pdf).

We want to know how the purposes we have in mind with these summer/winter schools have been experienced by the participants. Our research questions are by consequence:

RQ1: What’s the profile of the participants in these summer/winter schools?

RQ2: To what extent have the participants experienced our intended aim to support them in building an inclusive and international research community and in gaining domain-specific knowledge needed for their research?

To investigate these questions, we conducted an anonymous survey of the participants of the summer/winter schools organized in 2022. The following paragraphs present the survey design, sample, results, and discussion.

2 METHODOLOGY

The PhD students of both summer/winter schools received by email at the end of their school the invitation to participate at a very similar custom-made online survey.

2.1 Survey design

The 20 questions of the SEFI-survey prompted a mixture of

- background information (5 self-designed questions focusing on facts about involvement in EER);
- perception data (5 self-designed questions probing opinions on EER);
- evaluative data (10 self-designed questions focusing on the evaluation of the summer/winter school, more specifically community building and knowledge acquisition during the summer school).

The 21 questions of the AAEE-survey included a number of questions that were multidimensional and asked additional information compared to the SEFI survey. However, except for some slight differences in wording the questions reported in this paper were common to both surveys.

The questionnaires were distributed online to the participants of these winter/summer schools after completion.

2.2 Sample

The SEFI summer school 2022 was hosted by KU Leuven from 2-6 May 2022, and was attended by 31 participants who were PhD students at a European university, 2 were affiliated with an American university and one with an Indian University. The AAEE winter school 2022 under investigation was hosted by the University of Technology Sydney from 18-22 July 2022. There were 17 registrations, all from Australia, and unfortunately 3 participants cancelled because of illness.

24 PhD students filled in the SEFI-suvey, resulting in a 71% response rate and 9 participants (PhD students and transitioning researchers) completed all questions in the AAEE-survey, representing a 64% response rate.

3 RESULTS

3.1 Background information (5 items)

Most participants had less than 2 years of experience in EER (55%/67%). Before starting their PhD in or transition to EER, some of the participants first conducted TER (33%/56%), we call them the ‘switchers’. Most of these ‘switchers’ experienced a large to moderate skills gap while making their transition to EER (100%/80%). The

16 PhD students of the SEFI summer school who did not start in TER first, had less transition-problems (44% of them indicated that they had minor or even no missing skills).

There is a large variety in the size of the EER-research groups the participants belong to: 13%/20% of the PhD students are undertaking their research topic in isolation, most of them have 2 EER-PhD colleagues (58%/40%) and 21%/20% have more than 2 EER-PhD students as near colleagues. Although most EER-research groups are small compared to regular TER-research groups, most participants of the SEFI-summer school are not compensating for this by being engaged in an EER-network beyond their own institution (71%). In contrast, 63% of the respondents of the AAEE-winter school are active in an EER-network within or outside their state or even internationally.

3.2 Perception data (5 items)

We were interested in the attendee's reasons for becoming an EER-researcher. Participants were provided with a list of reasons from which they could choose or an option to enter another reason not listed. In both schools, most respondents chose to be involved in EER because of their 'personal interest in learning and teaching' or 'a desire to positively impact students' educational experiences and the engineering profession'. A very limited number of participants chose the answer 'opportunity to access additional funding' or 'a way of generating research without needing a large budget'.

A relatively large portion of the respondents experienced ambivalent support from their institution, faculty or department (50%/33%). At each summer/winter school there was only one PhD student present who did not feel supported at all and 46%/22% experienced strong support.

As expected, many respondents felt that EER is part of the engineering discipline (58%/89%) only 2/1 respondent(s) at each school disagreed. However, the participants of the AAEE winter school are not convinced that their university also regards EER as an engineering discipline.

Almost all participants of the SEFI summer school indicated they see themselves still being involved in EER in 5 years' time (92%).

3.3 Evaluative data (10 items)

It was our initial aim to survey with these 10 items the perceptions of the participants concerning the two goals of the summer/winter school, i.e., community building and knowledge acquisition, assessed using a five-point Likert scale (1 = 'Strongly disagree' to 5= 'strongly agree'). We have performed a confirmatory factor analysis on the two-factor structure of the 10 items, part of the SEFI summer school. This assessment has confirmed the internal structure of two scales:

- Items 1 – 8: community building (Cronbach alpha = 0.75)
- Items 9-10: knowledge acquisition (Cronbach alpha = 0.65)

Table 1 presents the descriptive statistics of the items. Note these 10 items were slightly adapted for the AAEE winter school ([a]) where a four-point Likert scale was used.

Table 1. Descriptive statistics of the evaluative data (5-point Likert scale for SEFI summer school and 4-point Likert scale for AAEE winter school).

	item	SEFI summer school		AAEE winter school	
		Mean ***(max 5)***	SD	Mean ***(max 4)***	SD
1	I met people with whom I will cooperate in near future	3.75	0.94	3.33[a]	0.71
2	I met people who will support me if needed	4.00	0.59	3.00	0.50
3	I experienced the added value of the diversity of the background of the PhD students in EER	4.63	0.58	3.78[a]	0.67
4	I experienced the EER-community as inclusive and welcoming to researchers from different backgrounds	4.67	0.48	3.56	0.53
5	I experienced the international character of this rapidly evolving field	4.75	0.44	2.11	0.78
6	I have a stronger identity as an EER researcher	4.08	0.93	2.33	0.71
7	I have an improved feeling of belonging to the EER research community	4.25	0.74	3.00	0.71
8	I have more confidence in the importance of this type of research	4.29	0.81	3.33	0.71
9	I have more methodological awareness and understanding of possible research designs	4.25	0.74	3.33[a]	0.71
10	I have the standardized terminology at my fingertips	3.63	0.97	3.33[a]	0.50

4 DISCUSSION

The profile of the participants of both schools (RQ1) is homogeneous (i.e., years of experience in EER) on the one hand, but also heterogeneous (i.e., experienced skills gap) on the other. It should not surprise us that most of the SEFI school participants were commencing PhD students since it was explicitly stated in the announcements that this was the focus of the schools. Conversely, the AAEE school welcomes any participants who wish to transition to or improve their capacity to undertake EER. The experienced skills gap was much greater among the switchers compared to the non-switchers. Switchers, on the other hand, have the advantage that they have to learn relationships among disparate fields of knowledge (cognitive complexity) and this increases their innovation potential (Akay 2008). We estimate that the SEFI switchers have a Master's degree in a technical field, but we cannot prove this explicitly because we did not ask for their prior education (in the AAEE school many switchers already hold a PhD in a technical field). Comparably, we did not ask their nationality or maturity. This might have provided useful insights to understand the difference between the two schools concerning the extent to which the participants engaged in an EER-network outside their university. Possible reasons for more AAEE than SEFI participants for maintaining external networks might be because there are very few universities in Australasia that have EER programs, requiring EER-researchers to seek support and maintain networks external to their university.

The participants are proud to undertake EER and selected EER as their research topic because of their personal interest and motivation to have impact on students' educational experiences and the engineering profession, in line with the third motivation for doing EER according to Borrego and Bernhard (2011). Despite these valuable objectives, they experience ambivalent support from their institution, faculty, or department. And the impact of this university environment on their development as an engineering education researcher cannot be neglected (Gardner and Willey 2018). But the good news is that Gardner and Willey (2018) also found that participation at an Engineering Education conference is an important contributor to identity and competency progression of EER-researchers at all stages of development.

And this brings us seamlessly to the second research question (RQ2) that focuses on the experiences of these doctoral students during the summer/winter schools. The participants experienced our aim to build an inclusive and international research community and to support them in gaining domain-specific knowledge needed for their research. The analysis of the evaluative data shows that the mean score of community building is 4.3 (SEFI summer school) and 3.8 (AAEE winter school rescaled to a 5-point Likert scale) and the mean score for knowledge acquisition is 3.9 (SEFI summer school) and 4.2 (AAEE winter school rescaled to a 5-point Likert scale). Possible reasons for the differences between the two schools in community building probably relate in part to the fact that the SEFI school is a residential school whereas participants in the AAEE school organise their own accommodation. In addition, many of the AAEE school participants are at different academic levels and at different stages of their career. This means they often have to undertake catch up work on their usual university activities during the evenings and hence are not socialising with the other participants out of school hours.

It is harder to speculate as to why there is a difference in the results in regard to knowledge acquisition. However, contributing factors could be that the AAEE school runs for five days while the SEFI school only runs for four days. The extra day allows for more participative activities to be undertaken during the school. For example, the AAEE school is very hands-on and includes discussions on participants' research interests and current research topics. Because of the limited time and the comprehensive content, the SEFI summer school was more lecture style. The authors experience suggests that the residential school suits the SEFI environment where all participants are PhD students and at similar stages of their career, where for AAEE a non-residential school has proved to be effective to meet the needs of participants who are often at different stages of both their research and academic careers.

A significant difference in the results for each school was in response to the statement “I experienced the international character of this rapidly evolving field.” The SEFI summer school participants experienced this feeling as the strongest, whereas the AAEE winter school participants scored this as the lowest. This is not surprising given the relative geographic isolation of Australasia. The only international exposure participants of the AAEE school receive is typically through the facilitators describing their networks or through discussions about the significant international EER conferences and journals. The opposite difference emerged when looking at “I have the standardized terminology at my fingertips.” It’s clear that the AAEE winter school was better in supporting the participants in knowledge creation, compared to the SEFI summer school. The latter is an important skill because the understanding of the international literature is an important prerequisite for quality scholarship (Bernhard 2018).

5 SUMMARY AND ACKNOWLEDGMENTS

Additional research is required to unravel the influence of specific personal or organizational characteristics on the perceptions of the participants. What can be confirmed is that the schools are helping to promote participation in and visibility of EER through developing research quality, capacity, and scholarship. They are also establishing an international network of researchers in EER (our future EER-professors) to encourage international collaborative research projects and papers about Engineering Education and the advancement of engineering.

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Development in students´ perceptions of sustainability and responsibility as relevant aspects of the role of engineers

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ABSTRACT

Engineering and technology-based solutions can address the global challenges associated with sustainable development. In this context, engineers have a substantial responsibility in achieving the Sustainable Development Goals (SDGs). Meeting the challenges of all SDGs influences economic, political and social aspects of human life. However, engineering students' understanding of sustainability is often limited to its ecological and economic dimension, not taking into account or even neglecting social issues. Therefore, teaching approaches in engineering education should address the different dimensions of sustainability and the responsibility of technological development concerning society.

This paper provides a case study on successfully addressing competencies related to sustainability and responsibility in the context of a mandatory lecture called "Engineering and Society" for undergraduate environmental and civil engineering students. With this work, we aim to discuss how engineering students can become aware of the relevance of social responsibility and sustainability through an introductory mandatory lecture. For this purpose, students' competency development and their knowledge acquisition related to social aspects of sustainable development are analyzed. It is investigated how far the lecture contributes to students' perception of sustainability and responsibility as relevant aspects of the engineering profession. To do so, on a quantitative level the self-assessment of competency development is analyzed, and on a qualitative level we analyzed the students´ self-perception of the role of engineers and their statements on learning gains and knowledge gaps after the lecture.

1 INTRODUCTION

To address the challenges of the Sustainable Development Goals (SDG), technology and engineering contribute significant solutions (UNESCO 2021). Engineers are for example jointly responsible for functional infrastructure in areas such as housing, transportation or water supply (UNESCO 2021). Systems they construct tend to be both expensive and long-term investments that get shaped by and do shape the people living within. Accordingly, responsible and sustainable engineering designs characterize an important challenge for future engineering professionals. This includes not only technological, economic and ecological, but also social aspects (Tabas, Beagon, and Kövesi 2019; Steuer-Dankert et al. 2019).
Engineering students are motivated to deal with social impacts of technology and to learn how to use technology for the benefit of all. There is also an interest in dealing with social issues in their education (Niles et al. 2020). However, research has shown that engineering students' understanding of sustainability is often limited to its ecological and economic dimension, neglecting social issues (Haase 2014; Segalàs, Ferrer-Balas, and Mulder 2010; Drake et al. 2023; Björnberg, Skogh, and Strömberg 2015). Using the framework of the SDGs in engineering education allows to enhance the necessary competencies of future engineers (Beagon et al. 2022). As identified by Beagon et al. (Beagon et al. 2022), social responsibility and sustainability awareness are relevant competencies of engineers. To sensitize students for these issues and to enable them to assess the effects of their decisions on society, teaching approaches for sustainable development in engineering education should address different dimensions of sustainability and also focus on the impact of technological development on society (Drake et al. 2023; Børsen et al. 2021). Moreover, students have different perceptions of engineers and their social responsibilities, which are influenced by family, media or practical experiences (Rulifson and Bielefeldt 2019). For this reason, courses within engineering programs have to offer opportunities to improve students´ understanding of social responsibility and its relevance for engineers (Rulifson and Bielefeldt 2019). In this paper, we present a case study on a flipped classroom concept, that has been developed for a mandatory course which many participants. For this purpose, we analyze the students´ competency acquisition in the context of this course, which focuses on social aspects of sustainability. It will be discussed which competencies are particularly strengthened by the implementation of a flipped classroom approach. In addition, the change in students´ perception of the role of engineers based on participation in the lecture will be examined.

2 STUDY CONTEXT AND METHODOLOGY

2.1 Lecture Concept

The context for this study is a bachelor´s course on "Engineering and Society" which is mandatory for all Bachelor students of civil and environmental engineering, and technical communication in their first year of study at RWTH Aachen University. The lecture takes place every summer semester and on average 400 students take part. "Engineering and Society" serves as an introduction to the interdependencies between gender, diversity, sustainability and engineering and teaches the significance of sustainability, ethics and social structures.The course is framed by the UN Sustainable Develoment Goals (SDGs) (Decker, Winkens, and Leicht-Scholten 2022). After an introduction of fundamental theoretical concepts, such as

sustainability or responsibility, current and global challenges of selected SDGs are considered to discuss the role of engineers in achieving them.
To structure the learning content, the lecture consists of three thematic blocks with eight learning units: (1) Fundamentals of a social and sustainable technology design, (2) Introduction to social structures, and (3) Tools for a sustainable habitat design. The first block provides the fundamentals for the following learning units and gives an insight into basic concepts and ideas of sustainability, responsibility, as well as ethics and technology assessment. After this, the second block deals with social issues, such as diversity, gender, discrimination or international cooperation (SDGs 5, 10, 16 and 17). In the third block, the previous theoretical foundations are connected to practical implications, such as urban planning, mobility and water supply (SDGs 6, 9, and 11).
The framing by the SDGs embeds the content of the lecture in a global context as well as illustrates the interface between engineering and the social dimension of sustainability. After completing the couse students should not only be able to analyze the connection between sustainability and responsibility and their relevance as well as the implications of the intersection between technology and society, but also discuss current issues with their fellow students and reflect on their responsibility as engineers.
Fig. 1 shows the structure of the one-semester course, where the learning units of each block and the related SDGs are shown. Because the course is offered in German, we translated all material into English.

Thematic Block	Learning Units	Related SDGs
Block I: Fundamentals of a Social and Sustainable Technology Design	Sustainability & Responsibility Technology Ethics & Assessment	
Block II: Introduction to Social Structures	International Cooperation Gender & Feminism Gender Equality Strategies & Diversity	
Block III: Tools for a Sustainable Habitat Design	Urban Planning Mobility Water Supply	

Fig. 1. Thematic structure of the lecture “Engineering and Society”

The teaching and learning concept of the lecture is based on flipped classroom principles, which have been iteratively developed over several years (for more information see Decker, Winkens, and Leicht-Scholten 2021, 2022). Self-directed learning, self-reflection and plenary discussion and reflection are the didactic focus of the lecture. The students work out the learning content independently with the support of various materials (self-directed learning). In addition, various offers are available for reflection on the content and to deepen the understanding of the learning content (self-reflection). For this purpose, students have the opportunity to reflect on their understanding of the lecture content in form of reflection papers on given questions. Discussion and reflection sessions for plenary sharing are offered during the semester.

2.2 Data Collection and Analysis

In the following, students´ competency development in the context of a flipped classroom course and their knowledge acquisition related to social aspects of sustainable development are analyzed, where both quantitative and qualitative data are evaluated. To do so, the self-assessment of competency development and the self-perception of the role of engineers of the students are analyzed.
Students performed a pre-post self-assessment of their competency development using pre-determined items on a five-point Likert scale: 1 – disagree, 2 – rather disagree, 3 – neither, 4 – rather agree, 5 – agree. The students answered 20 items, divided into five areas: knowledge and understanding (K1 – K7), methodological (M1 – M5), social (S1 – S2), personal (P1 – P3) and media (ME1 – ME3) competencies (see Table 1). In accordance with the competency model of the German Higher Education Qualification Framework (HQR) (HRK, KMK, and BMBF 2017), we understand the specific competency areas as follows: Knowledge and understanding are defined as knowledge processing, comprehension and deepening. Further methodological competencies include the use, application and generation of knowledge. Social competencies refer to communication and cooperation. Personal competence includes students' scientific self-image and professionalism. In this assessment, media competencies deal with the organization of the digital learning units. In addition, the survey contained items on motivational factors for participation and attitudes towards the lecture topics as well as on experiences with blended learning.

Table 1: Items of the self-assessment of competency development

K1	I know the different dimensions and aspects of the concept of sustainability.	M1	It is easy for me to recognize critical discourses as such and to deal with them reflectively.
K2	I know the Sustainable Development Goals in the context of sustainability.	M2	I am able to integrate sociological knowledge into engineering problems.
K3	I know the German ethical principles for engineers.	M3	I am able to independently develop learning content and acquire knowledge.
K4	I understand the relevance of the Sustainable Development Goals for my work as an engineer.	M4	I am able to assess my learning progress and check it independently.
K5	I am able to explain the relevance of ethical principles in engineering in my own words.	M5	I am able to write an argumentatively logical assessment of a given issue.
K6	I am able to explain the connection between social responsibility and sustainable development in my own words.	S1	It is easy for me to exchange ideas with my fellow students, to communicate and to discuss current issues.
K7	I understand my responsibility as a future engineer for society.	S2	It is easy for me to discuss my views in front of a large and unknown group.
P1	I am open to new things and can acquire new knowledge in a reasonable period of time.	ME1	I feel confident in using RWTHmoodle and can easily use the provided tools.
P2	I am able to assess the consequences of my decisions, so I act prudently and take responsibility for them.	ME2	I feel confident organizing learning materials provided online and keeping track of current assignments.
P3	I am able to adapt my usual thinking and actions to changed structures.	ME3	I feel safe participating in a discussion.

On a qualitative level, we analyzed students´ written thoughts on their self-perception of the role of an engineer as well as their learning growth and knowledge gaps at the end of the course. For this purpose, the free-text item "What role do engineers have in society" of the self-assessment was analyzed. The analysis was conducted by inductively categorizing students´ self-perceptions.

3 RESULTS

3.1 Competency Development

Of 426 students who participated in the course in 2022, 387 completed the pre- and 77 completed the post-self-assessment. The use of personal IDs preserved students' anonymity while allowing the analysis of matched pre- and post-data for n=44 participants in sample test.

A Wilcoxon signed-rank test for dependent samples was used to analyze the matched pre- and post-data of the students competency development. The test shows only for the competency area knowledge and understanding a significant higher self-assessment at the end of the course ($p<0.01$). Therefore, we examine the cumulative percentages of agreement and disagreement for the items of the four competency areas. Fig. 2 and 3 illustrate the competency development for knowledge and understanding as well as methodological competencies. The competency development during the course is shown by the cumulation of the percentages of the answers on the Likert scale of (rather) agree and (rather) disagree. The data indicates a positive development in many of the self-reported competencies. Except for the social competencies (S1 and S2) and the first item of the methodological competencies (M1) descriptive statistics show also the reported increase in competencies.

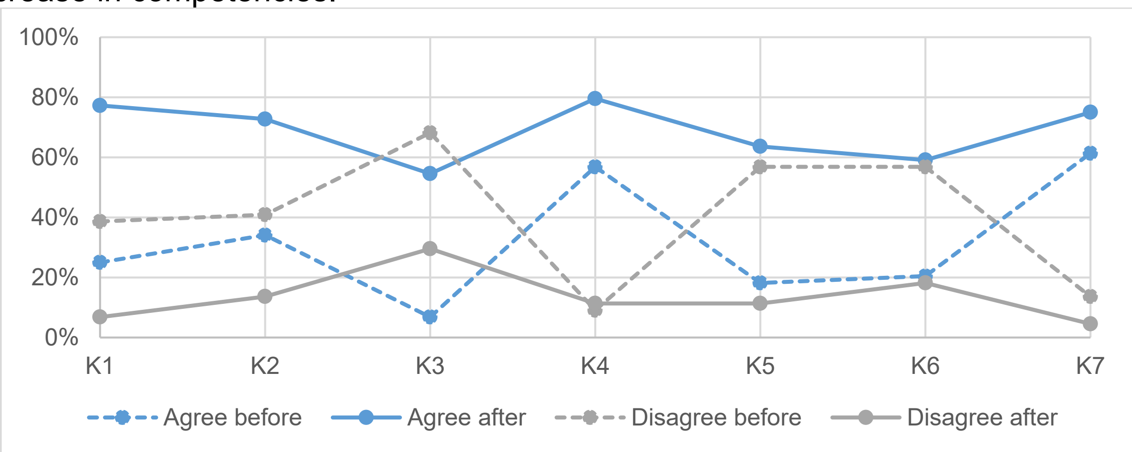


Fig. 2. Competency Development Knowledge and Understanding

Fig. *2* illustrates the competency development for the area knowledge and understanding. At the beginning of the lecture, only a quarter of the students were able to explain the concept of sustainability, one third knew the SDGs and only about seven percent had come into contact with the German ethical principles for engineers (see Fig. *2*). At the end of the course, about three quarters of the students know the concept of sustainability as well as the SDGs. In addition, more than three quarter of the students agreed with the items "I understand my responsibility as a future engineer for society" and "I understand the relevance of the SDGs for my work as an engineer". Answers suggest that participation in the lecture results in an increase of knowledge and understanding with regard to the learning content. Notably, especially the competencies related to knowledge acquisition are significantly higher after participation in the course (Wilcoxon test for dependent samples at $\alpha = 0.01$).

Fig. 3 shows the competency development for the competencies. After the course, one-fith more of the students report that they are able to assess and evaluate their learning process by themselves (M4). Positive competency development can also be seen for the independent development of knowledge (M2). Half of the students, up twelve percent from beginning, are according to their self-asssessment able to integrate socological knowledge into engineering problems. Furthermore, after the course, more students (nine percent) agree with the statement that they are able to write a argumentative logical assessment (M5).

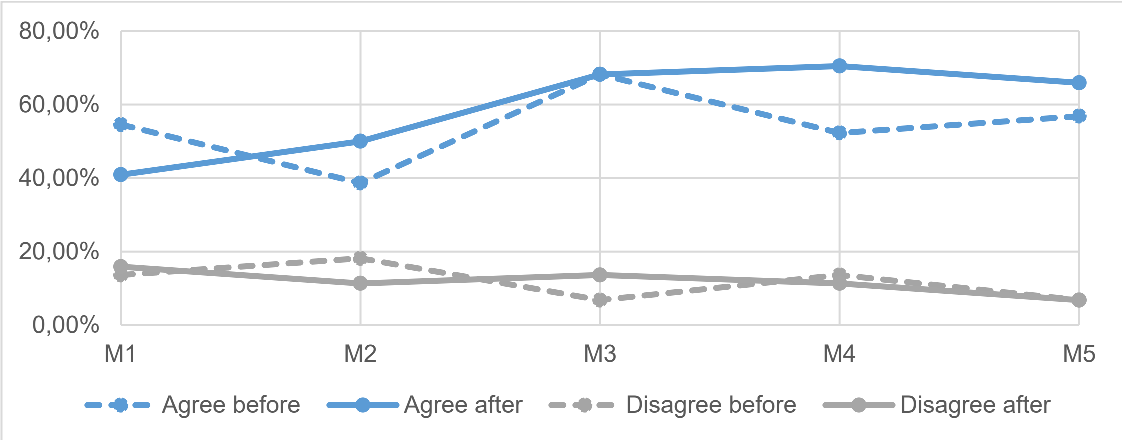


Fig. 3. Competency Development Methodological competencies

For the social competencies exchange of ideas with fellow students (S1) and discussion in front of a large group (S2), no positive development can be identified. Students´ agreement with these items remains unchanged between pre- and post-asessment with 32 percents (S1), and25 percents (S2), respectively.

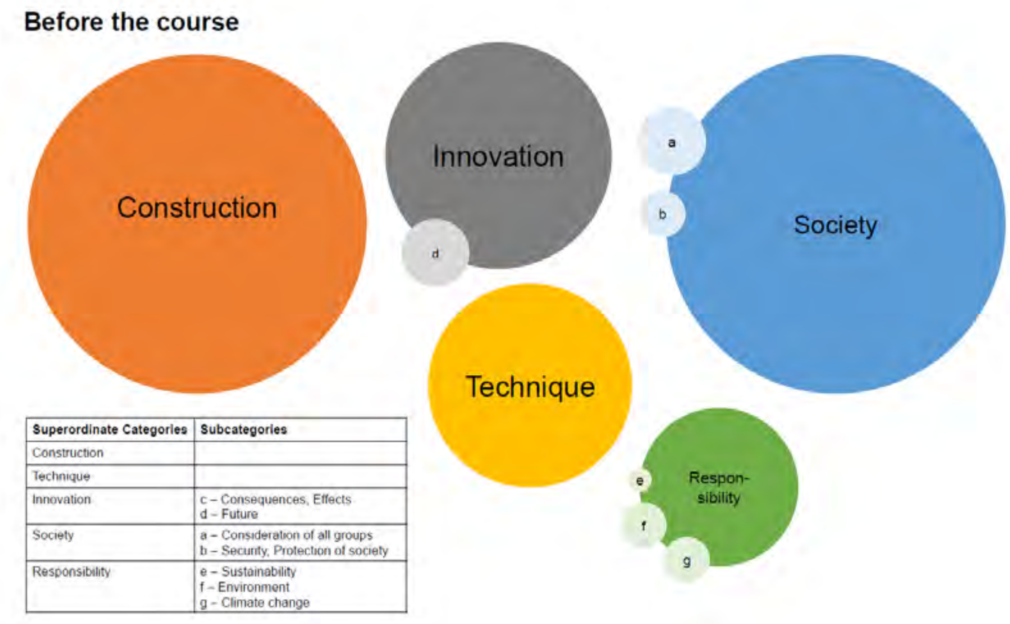
For the personal competencies (P1-P3), a change between the two assessments is only discernible for the adaption of habitual thinking and action to change structures (P3). Around three quarters of the students agreed with this statement after the lecture, a quarter more than before.

3.2 Students´ perceptions of their role as engineers

The high agreement of the students in the self-assessment on the ability to adapt their thinking and acting to change structures (P3) is also shown in relation to the perception of the role of engineers. The analysis of the free-text item shows a change in the perception after having attended the lecture “Engineering and Society”.

To analyze the free-text item “What role do engineers have in society”, we inductively formed categories from the available material to cluster the students´ statements and compare the pre- and post-data. The following superordinate categories emerge from the analysis*: construction, technique, science, innovation, society,* and *responsibility*. Fig. 4 and 5 show the assignments of the students´ statements to the superordinate categories and the subcategories (a–g). The size of the circles represents the frequency of assignment to the categories.

It is identifiable that students see construction aspects as an important element of the role of an engineer before and after the course. As the majority of students in this course study at the faculty of civil engineering, a focus on construction is to be expected. The pre-data analysis shows that students particularly associate the role of engineers with infrastructure construction, technology, and development, e.g., *“Planning and implementation of construction projects”* (ST16) or *“Developing and improving processes in their respective areas”* (ST17). Furthermore, some students describe the connections between building infrastructure and society, e.g., “*network* *social togetherness by creating housing structures, sports facilities, shopping facilities”* (ST19) or *“we engineers seek to improve and facilitate the lives of ourselves and those around us with new technologies” (*ST30). Few students are aware of the connection between technology and society.



Superordinate Categories	Subcategories
Construction	
Technique	
Innovation	c – Consequences, Effects d – Future
Society	a – Consideration of all groups b – Security, Protection of society
Responsibility	e – Sustainability f – Environment g – Climate change

Fig. 4. Assignments of the students´ statements to the superordinate categories and the subcategories (a–g) before the course

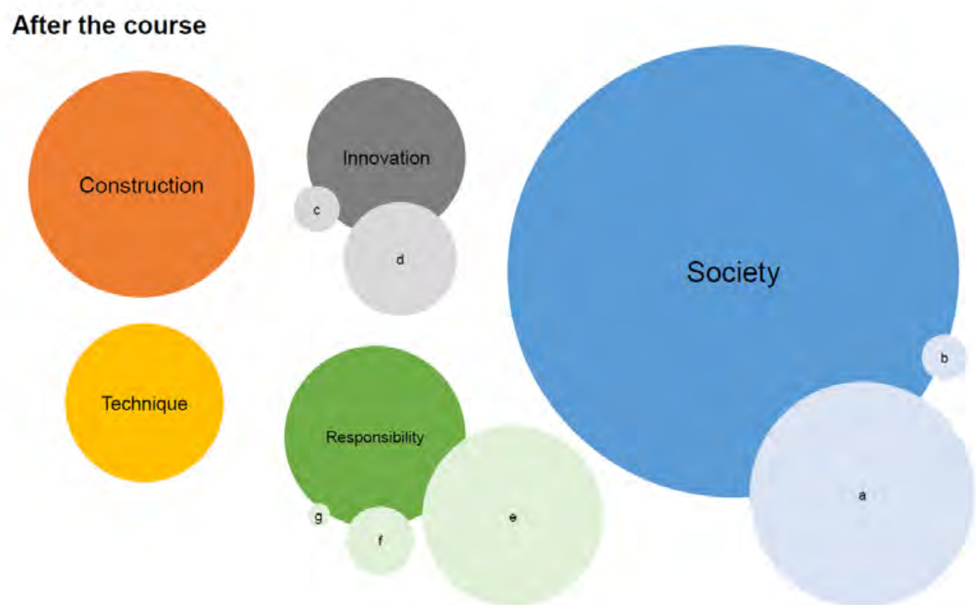


Fig. 5. Assignments of the students´ statements to the superordinate categories and the subcategories (a–g) after the course

The students' statements after the lecture are more frequently assigned to the categories *society* and *responsibility*. Thus, for the superordinate category *society*, the subcategory *consideration of all social groups* can be added after the analysis of the post-data. Students emphasize that "*all groups of society and their needs must be taken into account in the planning of any constructional undertaking*" (ST11). The results after the lecture show that in addition to incorporating societal needs into the planning of infrastructure, students also address the responsibility of engineers for sustainability and society as part of the role of engineers. According to the students' statements, engineers are "*shapers of a society*" (ST30) as much as "*solving future problems*" (ST41). In addition, they must "*take responsibility in areas that are relevant to all fellow human beings, but not everyone is equally knowledgeable and able to participate*" (ST36). The results of the free text analysis are in line with the positive competency development for the items K4 as well as K7 – both referring to social responsibility. In line with the observed changes in the self-perception of the role of engineers, students perceive the largest learning to have taken place in the area of social responsibility of engineers. In addition, in accordance with the quantitatively determined positive self-reported competency development (K1 and K2), students name sustainability and the SDGs as newly learned content. At the same time, students recognize knowledge gaps in these areas at the end of the lecture. In this context, they also formulate topics such as social responsibility, equality, diversity, and sustainability as knowledge gaps. When we asked about key questions that arise for the students at the end of the course, the students often answered with aspects regarding professional practice, e.g., "*How can I incorporate the knowledge I have learned into my professional life later on?*" (ST21) and the engineers´ awareness of social responsibility, e.g., "*How can we make it so that ALL engineers are aware of their responsibilities and live up to them?*" (ST38). This is also reflected in the quantitative data: Half of the students indicate that they are not better able to integrate sociological knowledge into engineering problems after the lecture (M2).

4 DISCUSSION

This study shows how a flipped classroom concept can promote different areas of competencies even in a mandatory bachelor course with many participants. The selection of the learning content addressing different dimensions of sustainability, focusing on the impact of technological development on society and referencing the SDGs, changes the students' perception of the role of engineers – a result that has also been illustrated by Drake et al. (2023) and Børsen et al. (2021).

About three-quarters of the respondents were interested in sustainability and social responsibility issues before the course but only a few of them were familiar with the concept of sustainability or social responsibility. Lectures on these topics in the first year of study can contribute to an acquisition of knowledge and understanding as well as changes in the perception of the role of engineers. After the course, the majority of students are motivated to engage with sustainability and social responsibility and to consider the issues in light of their engineering careers. This is also shown by the qualitative analysis: On the one hand, sustainability aspects and social responsibility play a larger part for students' perception role of engineers after the lectures. On the other hand, students still feel a lack of skills to integrate this knowledge into their work.

In term of methodological competencies, the strongest change is seen for the students´ability to assess and evaluate their learning process by themselves (M4). To implement the flipped classroom concept, a moodle learning platform is used. Through this students receive e-tests, glossaries and checklists to check and evaluate their learning progress. The positive development of the ability to write an argumentatively logical assessment (M5) is probably related to the various offerings for reflection on the content and to deepen the understanding of the learning content. The implementation of a flipped classroom concept, the division of the learning content into learning units, the various reflection and discussion options as well as the offers for monitoring the learning progress can also be useful for other mandatory courses with many participants, regardless of the topic of the course. The lecture “Engineering and Society” introduces topics related to social aspects of sustainability and social responsibility, but is not a teaching approach that promotes student learning in a particular way (R. Lozano et al. 2017). Lectures can promote the competency area knowledge and understanding as well as methodological competencies, while social competencies, as the results show, are not explicitly promoted.

After the course, more students (12 percent) than before perceive being able to integrate sociological knowledge into engineering problems. The selected basic sociological concepts and theories, i.e. diversity dimensions, development cooperation or social responsibility support this, as they are explained on the basis of the SDGs using concrete enginnering examples related to them.

The intended increase in knowledge in the areas of sustainability and social responsibility is not only evident in the quantitative analysis, but also in students’ perception of engineers’ role. Half of the students mention aspects which are covered in the two learning blocks “Fundamentals of a Social and Sustainable Technology Design” and “Introduction to Social Structures” (see Fig. 1) as relevant for their role perception. As Rulifson and Bielefeldt (2019) recommend, “Engineering an Society” offers a opportunity to understand the relevance of sustainability and social responsibility for engineers and to develop students' perceptions of them as engineers.

The data of this study are limited with regard to generalizability, because matched pre- and post-data are only available for 44 students. The data collection for competency development and the perception of the role of engineers is based on a self-assessment. Strengths and weaknesses of self-assessments for measuring competency development are discussed frequently (Redman, Wiek, and Barth 2021). Participation in the post-survey was voluntary, and only twenty percent of the students took part. Probably, interest in the lecture content and participation in the survey are related. Moreover, the participating students primarily study at the faculty of civil engineering, which is why the perspective with regard to the role of engineers here might differ from that of engineering students from other disciplines.

An introductory lecture, as the results show, can raise awareness about sustainability and social responsibility in engineering. However, based on this, follow-up courses are needed to systematically address the aspects formulated by students as knowledge gaps and to emphasize the linkage of social responsibility and sustainability with engineering and technical aspects, such as mobility, urban planning or clean energy. For example, the development of real case studies can be one further step to enable the students to apply their lecture-based gained knowledge into real-world experiences in the context of their education.

However, our qualitative results show that the discussion of sustainability and responsibility in the first year of studies can provide a change in students´ perception of the role of engineers and that students recognize the relevance of this for the engineering profession.

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FROM GROUP WORK TO TEAM WORK: COMPARATIVE ANALYSIS IN THREE EUROPEAN INSTITUTIONS

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ABSTRACT

Addressing the complex challenges of sustainability demands for good teamwork abilities for future technicians and engineers. In our three institutions we adopted

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project-based learning to facilitate the development of these skills – but is this enough? Since group project-based learning involves dealing with complex technical tasks and at the same time learning to work as a team, we wondered how students handle this double challenge. By analysing their perceptions, we attempt to identify what teaching practices could be helpful to shift their experience from groupwork to effective teamwork.

In this paper, we present the differences and similarities in the way we implement group projects in our respective institutions. A common questionnaire was proposed to our students capturing their perception 1) of the value of group project learning, 2) of their ability to carry out such projects in the future, 3) of the group perception of a shared goal and 4) of the quality of interpersonal relations within their group. Finally, we present the results of this first iteration of data collection showing different group profiles. We discuss the teaching practices that may contribute to sustain students' motivation for group-work and their confidence in their ability to achieve complex team projects, first in their academic context and then when facing challenges in their future employment within a changing world.

1 INTRODUCTION

The complexity and interdisciplinary aspects of sustainability challenges need to be addressed with a global mindset. In the twenty-first century, engineers are expected to "know everything", "can do anything", "work with anybody anywhere", "imagine and then make the imagination a reality" (Tryggvason and al., 2006). The question that follows is what is expected from students, and hence from their education?

Looking at the guidelines from the EUR-ACE® labelling agency, especially in the item "Making Judgment Communication and Team-Working" skills, expected Learning Outcomes include the ability to work in teams for handling complex problems with awareness of ethical and environmental issues.

Dealing with complexity and non-technical aspects of engineering, as well as being able to work in teams are part of what is expected worldwide from engineering students (Miller, 2015). This study reports on the ways three European institutions addressed the development of teamwork skills for future engineers and technicians through team-based projects. In this pilot project, by collecting answers to a common questionnaire from students in the three institutions, we aim to understand their perception of the quality of teamwork and of the way they experienced teamwork in project-based learning. Specifically, in comparing the three approaches our goal is to understand better 1) How do students perceive the group-work quality? 2) How do they perceive their skill development during projects? and 3) How they perceive the value of carrying out projects?

In the remaining of this introductory chapter, we present a concise literature review on role of project-based approaches in teaching scientific skills, followed by short presentations of each of the approaches.

1.1 Teaching computer science through projects - some insights from the literature

The subjects taught in engineering training are often complex and abstract. Active learning methods, such as project-based approaches tend to increase student engagement and in-depth retention (Freeman et al. 2014).

In project-based approaches, students must deal with complex and sometime ill-defined problems. Though engaging and persevering in the project can initially appear as difficult, when looking at the studies in motivation the challenges related to project-based approached have a positive impact on students' motivation and engagement. The students' motivation dynamic in learning (Viau, 1994) is rooted in the *perceptions* that a student has of (a) the *value of the task* that is to be done, (b) her or his *ability for performing* the task, (c) the *level of control* she or he has on the task implementation or choice. Team Project-Based Learning offers opportunities for meeting these motivation needs. Concerning the *perception of the activity value*, it seems that students tend to attribute high value in the project's tasks, more than on traditional labs tasks that are neutral and less engaging for students (Picard et al. 2022). Concerning the *level of control*, it is by-design in Project Based learning, for instance trough the choice of teammates, the task agenda, or the nature of the group production. Concerning *confidence in performing the tasks* involved by the project, offering resources and providing feedback help to make students feeling able to perform the activity.

Group-work offers multiple and various opportunities for receiving and giving feedback, both with the teacher and with peers, offering powerful support for learning (Hattie and Timperley 2007). Providing structured opportunities for feedback along the project helps students maintain their engagement throughout the projects. Even when such structured feedback is provided, students must deal with the difficulties of a long-term task, and of working with other people, which may be challenging for students used to more traditional frontal teaching. For exploring the effects of teamwork on students' motivation in project-based learning, Fernandez developed a questionnaire that measures two dimensions characterizing optimal teams: the perception of a common goal, and the rating of the quality of interpersonal relationship within the team (Fernandez, 2010).

Since team project-based approaches are implemented in different ways in our institutions, we use this questionnaire to compare them. The following section presents an overview of our approaches.

1.2 Teaching computer science through projects - how it is done in our three European institutions

In this part, we describe three project-based approaches respectively in HEG Geneva School of Management (*HEG*) at the Western Switzerland University of Applied Sciences and Arts HES-SO in Switzerland, at the University Institute of Technology of Annecy (*IUT*) from Université Savoie Mont-Blanc USMB in France, and in Polytech Annecy-Chambéry Engineering School (*Polytech*) from USMB.

Table 1. Summary of three project-based approaches

	HEG	IUT	Polytech
Level	Undergraduate	Undergraduate	Graduate
Duration	1 semester (Year 1)	1 semester (Year 2)	4 semesters (Year 3 to Year 5)
Country	Switzerland	France	France
Team size	2 to 3 persons	2 persons	5 to 10 persons
Study type	Working students	Alternants	Classic students
ECTS	3	1	17

The choice of projects topics, group setting, and assessment modalities are different, but their common goal is to support students in developing teamwork skills.

1.2.1 HEG Geneva School of Management (HEG)

The programme of HEG prepares students for technical careers, but with commercial aspects as well. Moreover, they need to be aware of the social, ethical and environmental implications of the technologies they are being trained in. Three years ago, a new first-year bachelor's module was introduced in the second semester, dealing with the Internet of Things (IOT). This was an opportunity to help students master multiple aspects of networking, such as sockets, protocols and device-to-device exchanges. We introduced a significant amount of team project learning into the module.

The first part of the semester focuses on hands-on labs that provide students with basic concepts that will be the "bricks" to be used during the team- project. It is assumed that students have prerequisites in python programming and computer networks. Topics are randomly assigned to students grouped by 3 by affinity.

The projects are designed so that they can be divided into 3 parts, each student being responsible for one of the parts. During the final presentation, students must be able to present the entire project, requiring them to explain strategic and technical choices of parts they were not responsible of. This fosters pair learning and team spirit (especially as the project and group are evaluated as an indivisible entity – all members of a group have the same grade). Nevertheless, cases of remarkable uncooperative behaviour are sanctioned individually.

Three teachers and an assistant supervise the practical work and guide them in solving the problems related to the project. A criteria grid for the assessment is given to students at the beginning of the course. The assessment of the project is at the group level and is based on a written report and an oral presentation/demonstration.

1.2.2 University Institute of Technology of Annecy (IUT)

The Learning and Evaluation Situations (LES) in the French University Bachelor of Technology (BUT) account for a minimum of 40% of the diploma's evaluation and are often structured as projects. They provide an opportunity for students to apply knowledge acquired from various teaching modules, which are in traditional form: courses, tutorials, and practical work. Several LES take place in each semester and each LES lasts no longer than one semester.

In this paper we focus on the approach adopted for the LES "development of dynamic web sites" at Réseaux et Télécoms dept of the IUT. This LES is associated to several modules: databases, algorithms, dynamic web and initiation to web, and is based on a problem-based approach, driven by clear functional objectives. Students work in pairs and choose their partners and well as a technical project (among several proposed or propose a new one). The problems are structured in a way that allows students to have well identified responsibilities. The evaluation grid and topic distribution are given in advance, with LES sessions scheduled to ensure students have time to complete the work. Teacher-mentored SOS sessions are available, and students are encouraged to explore additional concepts, with links and explanations provided. Choosing additional concepts is optional, and the teacher assists with the selection to ensure attainable challenges.

Final assessments of main module occur after the LES. Individual tests and quizzes are used to assess knowledge of the modules, while demonstrations and Q/A sessions are used to assess the LES. Self-assessments are required, and peer assessments are recommended. This organisation intends to raise awareness of skills learned and promote learning how to learn.

1.2.3 Polytech Annecy-Chambéry Engineering School (Polytech)

At Polytech project-based learning is adopted in several modules, but we focus in this paper on a particular project that is designed at the curricula level of SNI diploma (Numerical Systems – Instrumentation), providing opportunities for interdisciplinary integrative work as well as exploration of additional topics. The project starts in the second semester of Year3 and lasts till the first semester of Year5 accompanying the students throughout most of their learning journey in the engineering school.

The proposed projects have a wide spectrum and are susceptible to mobilize various knowledge acquired in other modules of the curricula, they are not dedicated to reinforcing any individual part of the program. Moreover, these projects work as a mean of colouring the diploma providing the opportunity for self-learning, as part of the material needed is not covered elsewhere in the curriculum. For instance, there is no Robotics module in the curriculum, but there is a Robotics project. The same occurs for the IOT.

Students express their motivated preferences for 2 out of the 5 subjects proposed by the teaching team. Their arguments are considered when forming the project groups, which entail between 5 and 10 students. Once established, the teams do not change, except for students failing their year or going in mobility. Thus, the students must make their team function properly, so if there are tensions, they must be solved. A small of group of teachers tutors each project.

Every semester there is a module in the curriculum that is assigned to the project, with ECTS assigned, and thus an evaluation. Each semester the evaluation is based on (1) a written report (group note by the project tutors), (2) an oral presentation/demonstration (group note by a teacher committee that entails all the group tutors), and (3) a half an hour interview with each one of the students (conducted by 2 teachers). The interview is built around the competences developed by the student (and registered prior to the interview in a Karuta portfolio). This exercise encourages students to reflect on their learning and on the choices to be made. They must connect the learning with the professional project. This kind of interview is presented as an interview managed by recruitment agency: no specific position, but an opportunity for candidate to explain what kind of job he/she desires. Students become aware that project provides argumentation (i.e., illustrated experience) to convince employers during interview. The preparation of the interview as well the exchanges with jury contribute to the self-efficacy development.

2 METHODOLOGY

In comparing the three approaches we tried to answer three leading questions:

- Q1 How do students perceive the group-work quality?
- Q2 How do students perceive their skill development during projects?
- Q3 How students perceive the value of carrying out projects?

We used a common questionnaire in our three institutions, for addressing these questions. The questionnaire and the data collection are presented hereafter.

2.1 Questionnaire

The questionnaire was constructed using questions demanding answers on the Likert scale (*strongly agree, agree, disagree, strongly disagree*). This uniform construction of the questionnaire allowed us to perform descriptive statistical analysis.

For answering Q1, we adapted the second part of the questionnaire of Fernandez (2010) for measuring students' perception of group work quality as represented by the perceived common goal and inter personal relationship.

The **Common Goal (CG)** represents how students perceive the group having a common target. The CG score is calculated from the answers to nine questions. The higher the CG score, the better: students perceive their groups as pursuing a common goal, rather than each member pursuing its own goal.

The Interpersonal Relationship (IPR) represents how students perceive the quality of interpersonal relations within the group. The IPR score is calculated from the answers to seven questions, on a four level Likert scale. The higher the IPR score, the better the students perceive the interpersonal relations in the group.

For answering Q2 **Skill developments (SK)**, we constructed four questions to address students' perception of developing skills that they will be able to use for carrying other similar projects in the future. An example of SK question is “I feel able of leading a technical project of the same type”.

For answering Q3 **Use value (UV)**, we constructed four questions to address their perception of the value of carrying projects in their education were included in the questionnaire. An example of UV question is “I can better project myself in a professional context (my employability has increased)”.

The SK and UV scores are also calculated using a four level Likert scale. SK and UV questions were designed in order to explore both the immediate perception of task value and the perception of the possible re-use of working on project skills in a long-term perspective.

2.2 Data collection

Students were asked to complete the survey on the Moodle platform of their institution. Table 2 shows the planning of data collection.

Table 2. Data collection –Autumn and Spring semester2022-23

Institution	HEG	IUT	Polytech
Date	14 January 23	20 February 23	24 March 23
Data	9 students, 4 groups	12 students, 6 groups	22 students, 4 groups

3 RESULTS AND DISCUSSION

3.1 Descriptive statistics

Table2 synthetize the results of our analysis. More precisely, for each one of the four dimensions (CG, IPR, SK and UV) we present the mean and standard deviation calculated from individual scores. For each person, an individual score for each of the four dimensions (CG, IPR, SK and UV) is calculated using the answers to the corresponding questions. The calculated score values range from 1 to 4. From these individual scores, and for each institution, the mean value and the standard deviation is calculated for each dimension (presented in Table 3). The comparison between the institutions is made using the Kruskal-Wallis test.
To measure the internal consistency, of the questionnaire we used Cronbach's alpha value for each dimension.
Results showed that the consistency of our SK and UV questions is comparable to that of the CG and IPR questions in the second part of the Fernandez questionnaire. In addition, the Cronbach’s alpha result indicates that our questionnaire is acceptable.

3.2 Comparison of Individual perceptions of group-work quality

<u>Having a common goal (CG):</u> whilst the value for the score is rather similar, we observed that the dispersion of individual answers tends to be lower for Polytech (SD of 0.37 *vs*. 0.45 and 0.47). This can be explained by the fact that the Polytech students are older, and the project duration is longer (4 semesters); the assumption

that there is a clear sense of common purpose among their teams is related to these elements.

Rating the quality of interpersonal relationships (RIP): IUT scored higher than the two other institutions. HEG and Polytech have the same scoring, but HEG scores are less homogeneous. We do not identify a convenient explication for these scores. Nevertheless, it is worth mentioning that both IUT and HEG have a “self-organisation model” as identified and discussed in (Bundgaard and al. 2021): they choose their group first. Topics are chosen later (IUT) or randomly assigned (HEG). As for the project allocation process used at Polytech, students choose the topics among existing proposals, teams are made according to the chosen topics, and the first semester is designed for team building; this approach is part of “subject-centred model” also studied and presented in (Bundgaard and al. 2021).

Table 3. Descriptive statistics - Internal coherence is acceptable for Cronbach alpha > 0.6 – Differences in the distribution of answers are considered significant for p < 0,05

	HEG		**IUT**		**Polytech**		**Tests**	
	Mean	SD	Mean	SD	Mean	SD	Cronbach α	Kruskal-Wallis (p)
Common goal	3.43	0.45	3.28	0.47	3.35	0.37	0.66	0.72
Interpersonal relationships	3.37	0.67	3.66	0.35	3.36	0.35	0.73	0.10
Skills development	3.30	0.49	3.27	0.51	3.01	0.51	0.69	0.17
Use value	3.04	0.50	3.31	0.53	2.86	0.51	0.74	0.06

3.3 Comparison of Individual perceptions of skills development and value of carrying out projects

Perception of developing skills for carrying other projects in the future: Polytech scored lower than IUT and HEG. Polytech students are halfway through projects that integrate many high-level professional and technical skills, assessed through a portfolio. Having this long-term perception of the project, they probably refer to the whole project when answering these questions, which nuances their answers. Moreover, the learning outcomes are situated at the highest level of the Bloom taxonomy (creation) (Forehand 2005), whereas in the others institute they are situated in the third level (application). Consequently, it is possible that Polytech students feel less like they are developing skills for carrying other projects in the future, and this could be another explanation of their lower score.

Perception of the value of carrying projects in the perspective of professional life: IUT students have the higher rating of the value of carrying project, followed by HEG students. For them, the project occurred at the beginning of the Bachelor, and, most importantly, they are already occupying professional position that are related to their field of education, increasing the perception of usefulness.

The better score of the IUT students can be explained by the fact that they project themselves easily in the applicative field of the project. For HEG, a significant part of the students does not project themselves in the applicative themes of the project, being more interested in the business part of their training. Nevertheless, the scores of these two institutes are relatively high, which can reflect the fact that the students are part-time students and know the company well, its needs and easily imagine the projection of projects in the company.

For Polytech, as for the previous indicator, the higher level of abstraction distances students from the "application" level, which can reassure the perception of their employability that these indicators show.

4 CONCLUSION

The main goal of our study was to compare the 3 approaches by answering 3 questions

- Q1 How do students perceive the group-work quality?
- Q2 How do students perceive their skill development during projects?
- Q3 How students perceive the value of carrying out projects?

The projects differ in different aspects, that are namely 1) the duration of the project, 2) the group size, 3) the level of control (the choice students have on group composition and project topic), and 4) the student profiles (employed/study-work *vs* full time students). These differences explain partially the results in the analysis presented in this paper.

It is worth noting that Polytech's project organisation has specific features: designed using competence-based approach inspired by Tardif (Tardif, 2006), its span (over the 3 years of engineering study) and its integrative and explorative nature make it rather unique (we did not find similar approaches in the literature). In the future experiments we consider including different projects from Polytech (shorter span, and more focused on specific topics).

The questionnaire used allowed us to answer the three questions, provided interesting insight for the 3 institutions and the answers are consistent with the way the institutions operate. The results, while allowing for comparisons between institutions, do not allow us to distinguish the contribution of each of the characteristics we have identified. In addition, the number of observations is clearly a limit to our study. In the measurements planned for the near future (this year and next academic year), we will modify some of parameters like for example, the student profile, increasing the number of students, giving the choice of projects when this was not the case, to study the impact. We will also include qualitative data from open-ended questions and focus groups. This will allow to deepen the analysis and confirm or not this first round of results and see how much they are dependent on the populations that answered the questionnaire.

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EXPERIENCES AND CAREER CHOICES OF FEMALE ENGINEERING UNDERGRADUATES IN CHINA

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***Keywords**: Female engineering undergraduates; Chinese higher education; Mixed-methods research; Career studies*

ABSTRACT

It is a global issue that the ‘pipeline’ leading to STEM occupations begins to ‘leak’ after graduation from STEM subjects, and the leakage tends to be much more severer for women. This study adds to current discussions on the underrepresentation of women in STEM fields, emphasizing the roles of gender and family engineering social capital in the career choices of female engineering students

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in China. The study follows an explanatory mixed-methods research design including a survey and interviews. The survey was completed by 508 Chinese engineering undergraduates at Chinese universities and created a quantitative descriptive landscape that situates the qualitative element of the study. Semi-structured interviews were conducted with 24 female engineering newly graduates to explain the underneath complexities of the quantitative discourse. Descriptive analysis of the survey data shows that women students, on average, tend to report higher engineering agency and more positive university experiences, but a weaker desire to pursue an engineering profession than men. This inconsistency can be partly explained by the qualitative finding that the hegemony of Confucianism shapes the specific gender norms towards engineering profession in China. Qualitative data also suggest that it is the “craze for Master’s degrees” in China that drives a number of women participants to take an MSc in engineering with the intention to work outside this field. However, having a family member working in engineering tends to provide overarching guidance for female engineering undergraduates to continue with an engineering profession.

1 INTRODUCTION

1.1 Background

Women’s underrepresentation in STEM (science, technology, engineering and mathematics) is a global issue, and engineering is one of the disciplines with the largest gender gap in representation. In China, as of 2020, 40.1% of all human resources in science and technology were female, while this percentage for engineering was only 31.7% (CAST and NAIS 2020). The ‘leaky pipeline’ to engineering occupations begins from the transitionary period from university to work and the leakage is reported to be much more severer for female students (Jan and Sean 2012). The transition of women in engineering from university to workplace is thus a crucial stage. This study aims to explore how Chinese female engineering newly graduates make career choices.

1.2 Gender and engineering aspiration

Gender-STEM stereotypes are regarded as an essential element in reducing women’s aspirations in pursuing a career in traditionally gendered disciplines disciplines. Gender stereotyping can be transferred and (re) produced implicitly and explicitly through daily interactions such as schooling and parenting (Beddoes 2021). Specifically, female engineering students at university have to tackle the probability that their performance might confirm the perceived stereotypes of women’s low aptitude for engineering subjects. This allows them to feel pressure against the gender constraints they experience at university. The climate in engineering programs can be chilly for women due to the male-dominated environment (Blickenstaff 2005; Walton et al. 2015). Such an environment can be a powerful structure contributing to women’s attrition in engineering. Family background is also emphasized by existing literature as a factor affecting engineering subjects and career choices of students, as they can be influenced by parents, who act as guides, role models and powerful agents, via communication and behavioural demonstration (Balakrishnan and Low 2016).

1.3 Post-structuralist understanding of structure and agency

Under the Foucauldian conceptualisation of power and structure, human beings are not simply under-goers of social experiences; instead, they take agentic actions in exploring and manipulating the structural environment. Agency and structure are not dualistic as they shape and are shaped by each other in a spiral, dynamic and conjoined manner of structuration (Fu and Clarke 2020). In this study, I particularly emphasize not merely the role of social constructions, but also how female engineering students interact, in different ways, with the social structures in Chinese societies where Confucian values emphasize highly gendered values and distinct gender roles have been deeply rooted for over two thousand years (Liu 2014). Being aware that structures are not unchanged or deterministic, I adopt post-structuralism to frame my research, regarding structure as fragmented and fluid. I aim at deconstructing processes of becoming by exploring changes socially and culturally constructed.

1.4 Research questions

This research considers engineering students' university experience and their schooling and family experiences as part of their educational biographies. This is because career decision-making is an ever-evolving process and engineering pathways contain a variety of behaviours that can be derived from adolescence and affected by social-cultural norms.

My overarching research questions are:

- How does gender shape Chinese engineering undergraduates' university experience, engineering agency and career aspirations?
- How do Chinese female engineering newly graduates make career decisions to continue or leave engineering?

2 METHODOLOGY

This study adopted a sequential explanatory mixed-methods approach, with a quantitative survey first and qualitative semi-structured interviews following. The survey targets engineering undergraduates from year one to year four at universities in China. It includes questions about students' agency in engineering, university experience and career aspirations. University experience is measured by 6 items which are drawn from the 'Student Persisting in Engineering Survey' (AWE 2007). Engineering agency includes 16 items from the 'Sustainability and Gender in Engineering survey' (Godwin 2014) as well as 'Agentic actions and agentic perspectives of career development survey' (O'Meara et al. 2014). Participants were instructed to rate each item using a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

With regard to career aspirations, as the research aims to examine whether engineering students choose to continue in or leave engineering as a profession, it identifies two distinct catergories of career choices: being inside and outside engineering. 'Engineering researcher at university/research institutes' and 'engineer at enterprise' were categorized as plans 'inside engineering', which are academic, professional and technical. Other types of jobs were categorized as careers and career plans "outside engineering".

A total of 508 students completed the survey, of which 31.1% are self-idenfied as women(N=158), and 68.9% are self-idenfied as man(N=350). Statistic descriptive analysis of the survey data has been conducted on SPSS.

The interviews included newly graduated female engineering students. The interview protocol covered topics related to 1) family experience, 2) schooling experiences, 3) university experiences, and 4) career aspirations. A total of 24 participants were recruited by the survey and snowball sampling where participants recruited from the survey were requested to refer just one new participant from their personal contacts, to minimize homogeneity and bias, of which 10 were choosing/planning to choose a career inside engineering and 14 outside engineering. Interview data have been thematically analysed.

3 RESULTS

3.1 Quantitative findings

T-tests were conducted to assess whether the means of two independent groups (women and men) were statistically different from each other. For reporting purposes, the level for statistical significance was set at 0.05

In Table 1, we can see that students in engineering programs reported a high level of engineering agency (means between 3.27 and 3.98). In particular, female participants report higher average scores than men students regarding most of the engineering agency measurements. They only report slightly lower scores in items 7, 8, 9 and 12 in Table 1, which are in line with existing literature suggesting that girls tend to have lower interest and lower confidence in learning engineering, as well as weaker engineering subjectivity (see Guo et al. 2015; Petersen and Hyde 2017).

Table 1. Engineering agency t-test results

Engineering agency items	Men Mean (SD)	Women Mean (SD)	P-value
1. I believe learning engineering will improve my career prospects	3.63 (1.075)	3.68 (.891)	.638
2. I believe engineering can help me see opportunities for positive change	3.50 (1.103)	3.60 (.944)	.311
3. I believe learning engineering can make me more critical in general	3.60 (1.100)	3.76 (.848)	.084
4. I believe engineering is helpful in my everyday life	3.56 (1.087)	3.70 (.899)	.116

5. I believe engineering will provide greater opportunities for future generations	3.45 (1.082)	3.64 (.883)	.037
6. I believe a country needs engineering to become developed	3.86 (1.087)	3.98 (.927)	.198
7. My parents/ relatives/ friends see me as an engineering person	3.50 (1.051)	3.35 (.965)	.147
8. I am interested in learning more about engineering	3.49 (1.073)	3.47 (1.001)	.819
9. I believe I can understand concepts I have studied in engineering	3.43 (1.068)	3.34 (.976)	.384
10. Others ask me for help in engineering	3.31 (1.082)	3.38 (.968)	.479
11. I can overcome setbacks in engineering	3.36 (1.060)	3.36 (1.005)	.971
12. My personal abilities/talents “fit” the requirements in engineering	3.47 (1.091)	3.27 (.980)	.043
13. I have been strategic in enhancing my engineering capability	3.39 (1.042)	3.52 (.936)	.169
14. I have intentionally made choices to focus on an engineering career	3.47 (1.056)	3.52 (.956)	.608
15. I have seized opportunities when they are presented to me to enhance my engineering capability	3.55 (1.008)	3.64 (.869)	.317
16. If I face a setback in the way of pursuing engineering, I take strategic steps to overcome the barrier	3.59 (1.025)	3.72 (.911)	.164

Table 2 shows that engineering undergraduates reported relatively positive university experiences, with mean scores ranging between 3.31 and 3.68. It is interesting to learn that female engineering students tend to rate these items higher than male students, in regard to workload, social interactions, classroom climate, group work, teacher-student relationships and role models. These results contrast with the “chilly climate” studies based on Western contexts (Blickenstaff 2005; Walton et al. 2015) and worth exploring in future studies.

Table 2. University experience t-test results

University experience	Men Mean (SD)	Women Mean (SD)	P-value
17. There is a reasonable workload of the engineering classes	3.48 (1.029)	3.54 (.857)	.508
18. I have positive and frequent interactions with engineering classmates	3.53 (.977)	3.57 (.832)	.627
19. There is a fair and inclusive climate in engineering classes	3.63 (.951)	3.68 (792)	.572
20. I often undertake important tasks in group work	3.40 (1.021)	3.41 (.806)	.925

21. Teachers are interested in me and confident in my professional ability	3.31 (1.028)	3.35 (.903)	.629
22. I have enough role models in the same gender, who can inspire me to work inside engineering in the future	3.37 (1.100)	3.49 (.936)	.234

When it comes to career aspirations of being inside or outside engineering, shown in Table 3, there are statistically significant differences between women and men students (p-value<0.01). 60.9% male students plan to choose a professional position inside engineering, while this number for female students is only 46.8%. Meanwhile, there is a higher proportion of female engineering students who do not have an explicit career plan (20.9% compared to 14.9% for male students), indicating a more urgent need on career guidance targeting female engineering undergraduates.

Table 3. Career aspirations crosstab results

			Inside engineering	Outside engineering	Unclear	Not sure	Total
Gender	Men	Count	213	57	28	52	350
		%within Gender	60.9%	16.3%	8.0%	14.9%	100.0%
	Women	Count	74	41	10	33	158
		%within Gender	46.8%	25.9%	6.3%	20.9%	100.0%
Total		Count	287	98	38	85	508
		%within Gender	56.5%	19.3%	7.5%	16.7%	100.0%

Integrating the above findings, we can conclude that women engineering students, on average, tend to report higher engineering agency, more positive university experiences but a weaker desire to pursue an engineering profession than their male counterparts. The interview data can help explain potential reasons for this inconsistency, which will be addressed in the next section.

3.2 Qualitative findings

3.2.1 Gender norms shaped by the hegemony of Confucianism

Strong gender essentialist mindset, gender stereotypes and discriminations shaped under the Confucian discourses have been reflected by participants, especially for those who choose/plan to pursue a career outside engineering. The conventional gender realm in China is asymmetrical with male privilege, and women were encouraged to take the role of virtuous wives and mothers in the service for the harmony of their families (Chiu 2016). Though those values have been gradually criticized, Confucian patriarchal values highlighting gendered values and roles have been entrenched in Chinese culture(Liu 2014).

Being an engineer is generally regarded as a high-paid but demanding job, this leads to both active and passive choices of leaving engineering for women. Regarding of the former, those women tend to be more sensitive to the gendered structures as so that they purposely avoid a “tiring although high-paid job” because they believe they bear less financial burdens:

> Men may be more suitable to engineering, because after all, men are indeed physically suitable for field work; (…) I think that men's pursuit of salary is stronger than that of women, because salary in engineering field is higher than in liberal arts fields……For women, I think it means that girls will not engage in field work or high-intensity manual work for high salaries, but men will. Comparing with salary, men tend not to regard health issue as important as girls do. (Mo, outside engineering)

This confirms the stereotyped gendered labor divisions that women are not motivated to earn money since men should be breadwinners. On the other hand, participants complained about the discriminations towards female jobseekers as a huge obstacle for their possible career path inside engineering.

> I would prefer an administrative position, because I think being a female engineer can sometimes be discriminated, such as in the maternity leave……A woman does pay a little more attention to her family in the future, I think, and then she may have less energy at work. (Hou, outside engineering)

> Just like some Railway company, if you are a girl, it will only let you do some clerical work like data clerk. And for management and technical positions, boys may be preferred. (Die, inside engineering)

In this light, even though female students tend to have more positive university experiences and engineering agency, powerful social and cultural structures, such as gender discriminations in the job market and Chinese traditional gendered roles, constrain their exercise of agency and prevent some women from practicing engineers or being an engineering professional. The gendered career environment in Chinese society can partly explain the differences between "engineering agency" and "engineering career agency", and between "an engineering student" and " an engineering career".

3.2.2 Family engineering social capital

Participants who choose a career 'inside engineering' tend to receive support from social relations during their educational biographies and interactions with social constructions. Parents or relatives who work in the engineering industry, provided emotional and material support from choosing engineering as a subject at university to a career after graduation. This resonates with the findings of Madara and Cherotich (2016) that having an engineer in the immediate family (engineering social capital), has a positive influence on their perceptions of engineering and thus supports their interests in pursuing engineering as a future career.

Xiang's family members motivated and inspired her to continue with engineering as a career after graduation:

> My cousin's aunt works at an engineering design institute and I think this is a job with relatively high social status. At that time, I forgot whether she has a Master's degree or not, but she worked very hard, and there were much more boys than girls in her class at that time, but she was considered the best. Her story inspired me a lot. I want to be a woman like her. (Xiang, inside engineering)

In a more practical and concrete way, Kai's father and cousin, both working in the civil engineering field, assisted her to find a job as a structure designer in an engineering design institute, when she was struggling with getting a Master's degree offer and the discriminations towards female job hunters in this industry:

> It was my family who helped me find this job, my dad and my cousin. It's hard to find a job for an engineering girl. Taking the design institute I am in now for example, if I only rely on myself, such as my university background and my bachelor's degree, it wouldn't accept me at all. For a girl, only if you have a master's degree or you are from a well-known university with excellent academic performance, I think you then have the chance to be accepted by this institute. That's the status quo. (Kai, inside engineering)

Engineering-related social support tends to empower female engineering students to resist gendered structures and exercise their agency to persist in this male-dominated field.

3.2.3 Degree-driven model of pursuing a MSc in engineering

There is a special group among my participants who (plan to) further their study in engineering but propose to leave this professional area after graduation(N=9). A common justification for their choices is that securing a Master's degree is more significant than choosing a program they are interested in.

> Learning geological engineering means that you can't avoid working in a harsh environment where many people don't want to go, so the competition is not that severe. It's relatively easy to pass the post-graduate entrance examination. This is also one of the reasons why I choose this master program. (Hou, outside engineering)

> Everything was on the premise that I could be accepted as a postgraduate student. I didn't have too much loyalty to the choice of subject to learn, as long as I can be enrolled. (Ren, outside engineering)

With the increasingly severe unemployment situation of undergraduates and the trend of "educational inflation" in China, a Master's degree has become the choice of more and more undergraduates. Choosing the same or similar subject as their undergraduate program tend to improve the chance of being successfully enrolled by a post-graduate program. In this case, even if some participants intend to leave this area when landing a job, they still choose to learn engineering for their post-graduate study. This can be interpreted as agentic conformity to the educational structure in Chinese contexts.

SUMMARY

This paper presents how Chinese female engineering students make career choices. Specific cultural gender norms in family and work perform as obstacles to women's pursuit of an engineering career. Together with the influence of "educational inflation" in China, some female participants choose to continue with the academic research training in engineering with the intention to leave this field after getting a Master's degree. Therefore, even though they tend to have more positive university experiences and higher engineering agency, fewer women choose engineering as a profession than men. Nevertheless, the study findings suggest that having family members working in engineering can assist women to resist gendered social constructions. Family engineering social capital can support women's interest and perseverance in engineering education, and help secure a position in this industry.

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SUSTAINABILITY ENGINEERING EDUCATION – AN OUTLOOK ON UK HIGHER EDUCATION PROVIDERS

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ABSTRACT

The aim of this paper is to assess the extent to which United Kingdom (UK) universities are incorporating sustainability into their engineering curricula. To achieve this, data from the Universities and Colleges Admissions Service (UCAS) and university websites were analysed using a text mining approach. The findings reveal that UK higher education providers are gradually increasing their offerings of Sustainable Engineering (SE) courses at both undergraduate and postgraduate levels. The most prominent sustainability themes integrated into engineering curricula are energy, design, and construction. Furthermore, the analysis of courses and their modules shows that 50% of UK postgraduate sustainable engineering courses contain between 25% and 50% sustainable engineering content. In contrast, almost one-third of traditional engineering courses that incorporate sustainability contain between 10% and 25% of sustainable engineering subjects. The study also examined the SE courses and their module descriptions to identify gaps and how UK higher education providers are contributing towards the United Nations Sustainable Development Goals (SDGs). The most dominant SDGs addressed in the UK SE courses analysed are SDG 7 Affordable and Clean Energy, SDG 9 Industry, Innovation and Infrastructure, SDG 11 Sustainable Cities and Communities, and SGD 13 Climate Action. This paper provides valuable insights into the integration of sustainability into engineering education and its alignment with the SDGs.

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1 INTRODUCTION

The global expansion of sustainable development principles over the recent years shows how important integration of sustainability in the engineering curriculum has become for Higher Education (HE) providers. Universities are taking an important role in vocational and skills training for sustainable development (SD) and it is being offered mostly at postgraduate than undergraduate level. Despite the inclusion of sustainability in engineering education in recent years, there are still challenges in the curriculum design and learning environment, and how the adoption of these curricula aligns with 17 United Nations Sustainable Development Goals (SDGs) and their priorities (United Nations, 2015, 2016).

Integrating sustainability competencies in engineering education is challenging and often lacks strategic and systematic planning (Beagon et al., 2023; Jordi Segalàs Coral, 2009, pp. 14–21; Leifler & Dahlin, 2020; Perpignan et al., 2020). Miñano Rubio et al. 2019) in their studies suggest that an appropriate model for systematically developing sustainability competencies within the engineering curriculum should be based on three pillars, such as the inclusion of sustainability principles in compulsory courses and in academic project activities, and lastly embedding sustainability content into appropriate courses along the curriculum.

Another challenge is the sustainability content in the engineering programs and how the implementation of sustainability content into traditional engineering courses benefits students and SDGs. In Australia and elsewhere, studies were conducted to understand the current status of universities regarding the implementation of sustainability content in engineering curricula (Arefin et al., 2021; Balakrishnan et al., 2021; Filho et al., 2021; Monna et al., 2022; Murphy et al., 2009; Sánchez-Carracedo et al., 2022; Thürer et al., 2018). Environment and Energy was the most common theme stated in these studies. Studies elsewhere also found that ethical and social sustainability issues do not appear explicitly, there is still a need for understanding the expectations and skills sought by future employers and how universities can integrate them the engineering curriculum (Akeel et al., 2019; Edvardsson Björnberg et al., 2015; Kamp, 2006).

Moreover, some studies have have looked into the insight of modes of course delivery adopted by universities related to the implementation of SD in their engineering curricula, among others stand-alone courses (Hegarty et al., 2011), integrated sustainability content into conventional engineering curricula (Zanitt et al., 2022), continuous professional development courses (Pérez-Foguet et al., 2018), online or distance learning (Simson & Davis, 2022). Despite the challenges discussed in these studies, there is a focus on the learning objectives to be met regardless of the delivery mode. A guide for universities around the world has been published to accelerate action on SDGs (SDSN Australia/Pacific, 2017) and how universities can incorporate sustainability into engineering programs among others (RAENG, 2005; UNESCO, 2021).

Given (i) the urgent need for aligning, not only the objectives of HE, but also the means that develop competencies, with the sustainable trajectories that modern societies are willing to undertake, (ii) the role of the sector in shaping the mindsets and enhancing the skillsets of the leaders of the future, and (iii) the circular role of sustainability in HE, this paper aims to provide an outlook of the undergraduate and postgraduate engineering courses offered by the United Kingdom (UK) higher education providers that address sustainability engineering in their curriculum for improving observability of current situation and triggering actions towards the necessary direction. The paper is organised as follows; Section 2 presents the methodology that has been used in this study and provides the necessary details about the data gathering, processing and analysis. Section 3 presents the key outcomes of the analysis and discusses the results, while Section 4 concludes the paper and indicates possible extensions as future work.

2 METHODOLOGY

According to the Universities and Colleges Admissions Service (UCAS), there were over 50,000 HE courses available in the UK in 2021, including undergraduate and postgraduate programs across different fields of study, while the engineering and technology-related subjects were among the top five most popular subject areas for higher education in the UK, with over 302,000 students enrolled based on data from the Higher Education Statistics Agency (HESA). This number includes both undergraduate and postgraduate programs from 165 HE providers in various fields of engineering, such as mechanical engineering, electrical engineering, civil engineering, and chemical engineering, among others.

To grasp an overview and analyse the trends in the UK higher education sector around the integration of sustainability in the engineering curricula, a structured navigation method to process the available information with emphasis on the present (2022-2023) and next academic years (2023-2024), and a text-mining-based approach were deemed suitable. Therefore, an adaptation of the generic “Cross-Industry Standard Process for Data Mining” (CRISP-DM) methodological framework (Miner et al., 2012) was introduced, with the phases being presented in Figure 1.

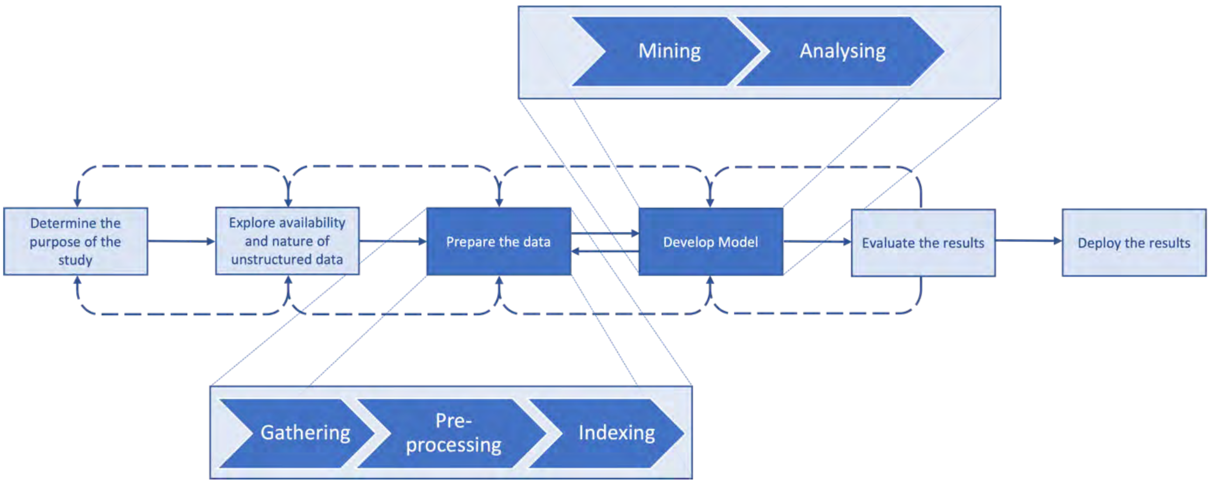

Figure 1: The introduced methodological framework that follows the phases of CRISP-DM. Adopted from (G. D. Miner et al., 2012).

Following the six phases of CRISP-DM, first, the study’s purpose and objectives were defined and then the data requirements and sources were identified, with the initial data collection and exploration being performed and potential issues or opportunities were identified, including more specifically, the higher education providers and details of the relevant undergraduate (UG) and (PG) postgraduate course they offer. Next, in the data preparation phase, the data, including the underlying themes covered in the UG and PG courses as well as the sustainability-related content in the PG “sustainability-” and “conventional-” engineering programmes, was cleaned, transformed, and pre-processed to make it suitable for the model phase. The activities (Turegun, 2019)can be considered as follows:

- Gathering - Data collection from various sources e.g. document files, websites, emails or comments, with the process being either automated or directed by the user.
- Pre-processing - Identification and extraction of descriptive characteristics from content, by removing unwanted information (text clean up), breaking the text into meaningful units (tokenization) and measuring dimensions of the text (feature extraction).
- Indexing - Particular terms are indexed with the location and the number being noted so that that the structure will allow rapid access and efficient processing of the data.

It should be mentioned that data was extracted from the Universities and Colleges Admissions Service (UCAS) and UK universities' websites. A combination of 'Engineering' and 'Sustainability' words was used in the processing activity of university-level engineering curricula, and the frequency and association between words were used to create dimensions. A total of 38 UK HE institutions were found for both undergraduate ($N_{UG} = 10$) and postgraduate ($N_{PG} = 28$) levels that had a combination of target search terms in the course title.

In the model phase, the following activities took place in a structured and supervised manner, with rules and subprocesses being dictated by the nature of the problem and the pre-processing outcomes.

- Mining - Disclosure of new information through data exploration methods for revealing specific terms, their relation between other terms and their connection to semantic representations and taxonomies.
- Analysing - The analysis utilises the raw outcomes of the mining phase, by evaluating and visualizing them according to the problem at stake the user preferences, so interpretations can be made.

More specifically, as part of the mining activity, the UG and PG courses were clustered [ref] into main engineering themes, as these were identified and formed a short dictionary consisting of the entities “Environment”, “Energy”, “Transport”, “Construction”, “Building”, “Chemical”, “Design”, “Marine”, “Propulsion”, and “Business and Management”. Moreover, an indicative example of the analysing activity constitutes the extraction of the sustainability content index, for which the level of sustainability-related content in engineering PG programs was analysed. The data that was collected from publicly available PG courses information during the data preparation phase included module descriptions of several Aeronautical ($N_{Aero} = 22$), Mechanical ($N_{Mech} = 69$), Civil & Building Management ($N_{Civil} = 99$), Materials & Manufacturing ($N_{M\&M} = 40$), Design ($N_{Dsgn} = 10$) and Sustainable Engineering ($N_{Sust} = 44$) programmes. Finally, by focusing on the Sustainable Engineering PG courses their contribution to SDG goals was analysed by identifying and categorised components of the curricula.

Finally, according to the methodological phases, the outcomes and results were evaluated (Allahyari et al., 2017) (human evaluation) and triggered a feedback loop for corrective actions on the previous phases, while the deployed results of the analysis that are presented and discussed in the next Section of the paper, complete the process.

3 RESULTS AND DISCUSSION

In this section, we present the results of our research, which aim to provide an understanding of the underlying trends of UK engineering curricula towards SDGs. The data collected and analysed correspond to two subsequent academic years, i.e., the current one, 2022-2023 and the upcoming one, 2023-2024. We start by analysing the total number of UK Higher Education universities integrating Sustainable Engineering in their curriculum at both Undergraduate and Postgraduate levels, as depicted in Figure 2.

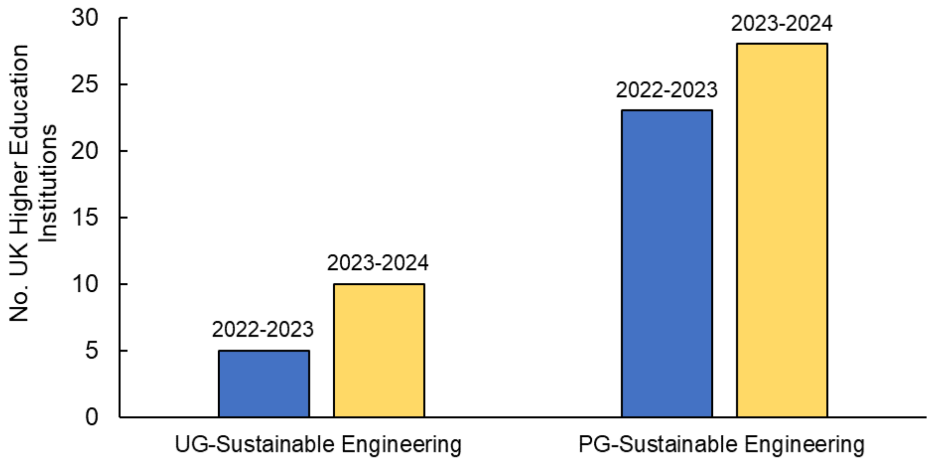

Figure 2. Integration of Sustainable Engineering into UK Higher Education Institutions' Curriculum

The number of UK Higher Education Institutions providing Sustainable Engineering undergraduate programs has doubled from 5 in the 2022-2023 academic year to 10 in 2023-2024. This indicates a 100% increase and could suggest a growing interest and focus on sustainability in engineering education. This is consistent with global trends towards more sustainable industrial practices, including engineering.

Moreover, at a postgraduate level, an increase is observed from 23 in the 2022-2023 academic year to 28 in 2023-2024, showing a growth rate of 21.7%. This suggests a continued emphasis on developing professionals in this field who can contribute to sustainable solutions at a higher level.

A more detailed review of the above findings has been conducted in terms of 'engineering theme focus'. Figure 3 illustrates the percentage distribution of different subject areas incorporating Sustainable Engineering content in their undergraduate (UG) and postgraduate (PG) programs across the two academic years 2022-2023 and 2023-2024, respectively. Comparing the data for UG programs between the two academic years, there is an increase in the percentage of Energy from 40% to 50%, while there are minor changes in the other areas of study. This suggests that there is a growing emphasis on Energy in the UG Sustainable Engineering curriculum.

In the case of PG programs, the percentage of Energy is highest at 47% for 2022-2023 and slightly drops to 45% in 2023-2024. Design, Construction & Building, and Environment have significant percentages ranging from 8% to 16% over the two academic years. Propulsion and Chemical have lower percentages ranging from 2% to 5% with minor fluctuations, while Business & Management, Transport, Industrial Systems, and Marine have lower percentages ranging from 2% to 5% and remain relatively consistent.

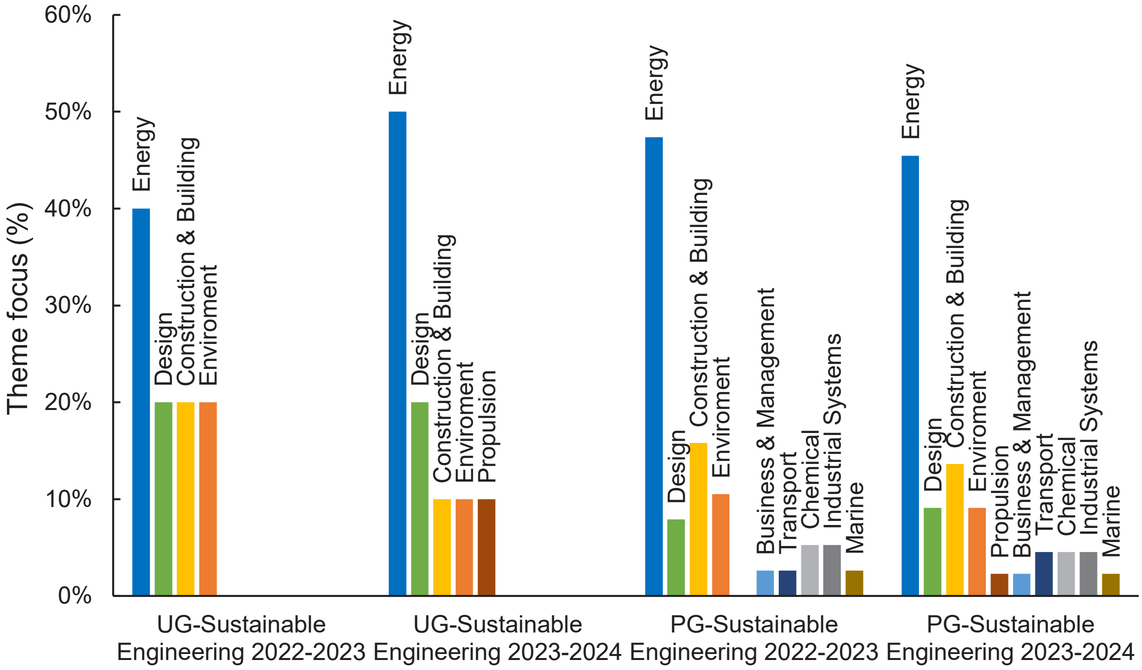

Figure 3. Themes covered in UK HE sustainable engineering courses (%)

Further analysis has been conducted on the distribution of sustainability content across various Postgraduate level Engineering programs. These programs fall into the following disciplines: Sustainable Engineering; Mechanical Engineering; Aerospace Engineering; Civil & Building Engineering; Materials/Manufacturing Engineering; and Design Engineering. And the data is categorised into five levels showing what percentage of the course content is focused on sustainability:

- 0%: No sustainability content
- 1-10%: Low sustainability content
- 10-25%: Moderate sustainability content
- 25-50%: High sustainability content
- >50%: Very high sustainability content

The data in Figure 4 showcases that PG-Sustainable Engineering notably exhibits a robust presence of sustainability content, with no modules having 0% sustainability content. Most of the modules are spread across the 1-10% (10), 10-25% (23), and 25-50% (11) categories. However, no modules primarily focus on sustainability (>50% content). PG-Mechanical Engineering and PG-Aero Engineering lean heavily towards lower sustainability content. In Mechanical Engineering, the majority of modules (45) show no sustainability content, with a small number falling within the 1-10% (23) and 10-25% (1) categories. Similarly, Aero Engineering has a significant number of units (17) with 0% sustainability content and fewer units (5) with 1-10% content.

Moreover, PG-Civil & Building Engineering and PG-Material/Manufacturing Engineering show some focus on sustainability. Despite a high number of modules (63) with 0% sustainability content in Civil & Building Engineering, it also presents a considerable number of modules (31) with 10-25% sustainability content. Material/Manufacturing Engineering has 26 modules with 0% sustainability content and 14 modules with 1-10% content. Finally, PG-Design Engineering, having the fewest modules, presents 3 with 0% sustainability content and 7 with 1-10% content.

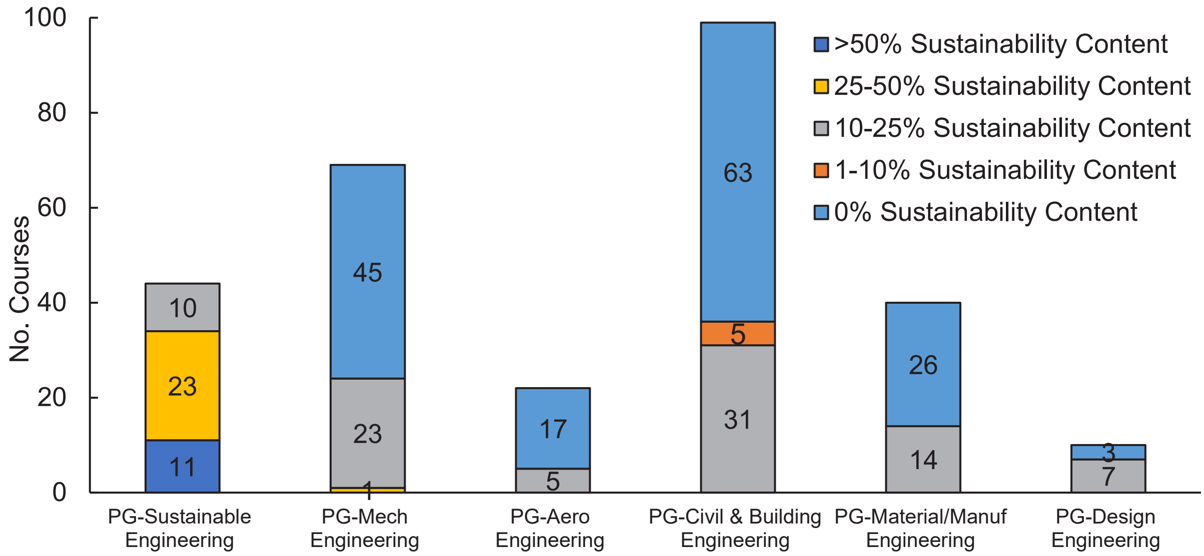

Figure 4. Sustainability Content across PG Engineering Disciplines

As a final step to our study, we attempted to identify the number of undergraduate (UG) and postgraduate (PG) courses offered across various UK institutions and map their curriculum with the 17 Sustainable Development Goals (SDGs) that the United Nations established in the '2030 Agenda for Sustainable Development'. The following data is illustrated in Figure 5:

- **SDG 3: Good Health and Wellbeing** - A total of 19 courses are offered, with 2 UG courses and 17 PG courses. This reflects the importance of health and wellbeing in the educational landscape.
- **SDG 2: Zero Hunger** - Only 2 engineering courses are available, both at a PG level. This suggests that there may be a need for more educational opportunities to address hunger and food security issues.
- **SDG 6: Clean Water and Sanitation** - There are 7 courses in total, all of them being PG courses. This may imply that water and sanitation issues are primarily addressed at a more advanced educational level.
- **SDG 7: Affordable and Clean Energy** - With 44 courses (5 UG and 39 PG), this SDG has a strong representation in the educational sector, indicating a focus on clean energy and its importance for sustainable development.
- **SDG 8: Decent Work and Economic Growth** - This goal has only 2 courses, both being PG courses. This may suggest that more attention could be given to promoting economic growth and decent work through education.
- **SDG 9: Industry, Innovation, and Infrastructure** - A total of 19 courses are offered, with 3 UG and 16 PG courses. This shows a considerable interest in fostering innovation and infrastructure development.
- **SDG 10: Reduced Inequalities** - There are only 2 PG courses addressing this SDG, indicating that more educational opportunities could be developed to tackle inequality issues.
- **SDG 11: Sustainable Cities and Communities** - This goal has 24 courses in total (3 UG and 21 PG), reflecting a strong focus on urban planning, sustainable development, and community-building.
- **SDG 12: Responsible Consumption and Production** - With 7 PG courses, this goal has a moderate representation, which could be further expanded to promote sustainable consumption and production practices.

- **SDG 13: Climate Action** - This SDG has the highest number of courses (45), with 6 UG and 39 PG courses. This demonstrates the increasing emphasis on climate change mitigation and adaptation in education.
- **SDG 14: Life Below Water** - A total of 6 courses are offered (1 UG and 5 PG). This suggests that there is some focus on marine conservation and life below water, although it could be expanded further.
- **SDG 15: Life on Land** - With only 4 PG courses, this goal has relatively limited representation, indicating a potential need for more educational opportunities focusing on terrestrial ecosystems and biodiversity conservation.

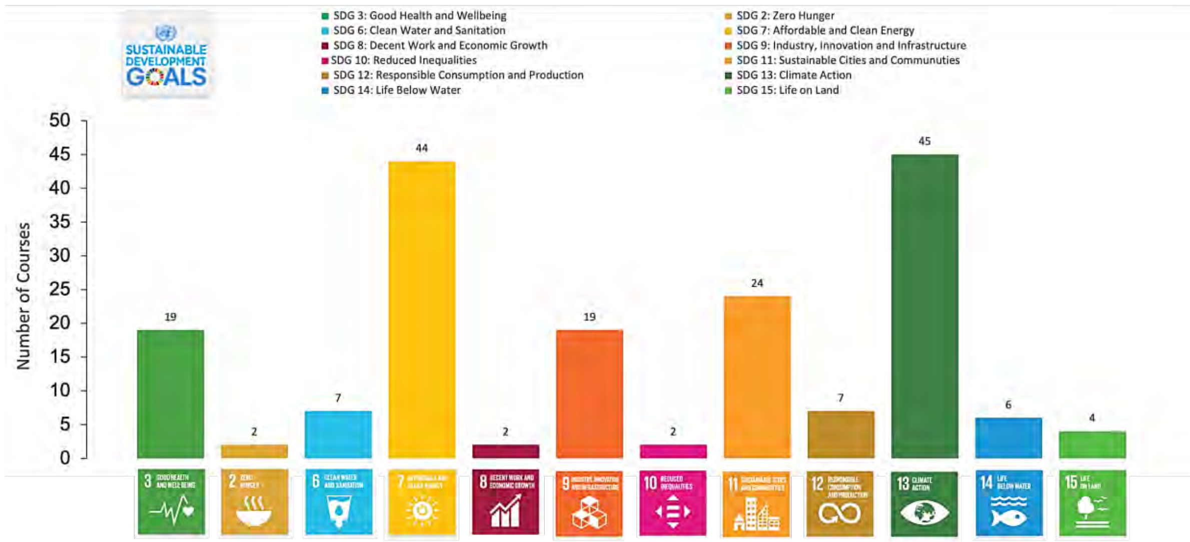

Figure 5. UK Sustainable Engineering and Sustainable Development Goals

To summarise, while certain SDGs like Climate Action, Affordable and Clean Energy, and Good Health and Wellbeing have strong educational representation in engineering courses, others like Zero Hunger, Decent Work and Economic Growth, and Reduced Inequalities could benefit from more courses to address their respective issues. It is also noteworthy that most of the courses offered are at the postgraduate level, suggesting that undergraduate programs could be further developed to encompass more SDGs.

4 CONCLUDING REMARKS

This study aimed to provide an outlook of the UK higher education providers towards SDGs initiatives in engineering curricula. A text mining approach was used to collect data from UCAS and universities website to look at trends and sustainability content in engineering courses in the UK. The data show that sustainability contents are being implemented in more than 46% of the sampled UK PG engineering courses (N=286), and the most prominent sustainability theme focus is Energy for the 2023-2024 academic year offer. More effort is needed by UK HE providers on the curricula development and provision of other themes towards SDGs including Product Desing and Sustainable Manufacturing.

In future work, we will analyse the integration of Social and Corporate Responsibility, and Ethics inclusion in UK engineering curricula.

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RESULTS OF SURVEYS AMONG PUPILS, STUDENTS AND EMPLOYERS ON INTERESTS IN AND CONTENTS OF STUDY PROGRAMMES IN CIVIL ENGINEERING, GEODESY, ENVIRONMENTAL SCIENCES AND SUSTAINABLE MOBILITY IN GERMANY

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ABSTRACT

The shortage of skilled workers in the engineering sector threatens the development and sustainable transformation of the economy in Germany. In this context, the current de-cline in the number of first-year students in civil engineering, environmental engineering, geodesy and traffic engineering appears all the more alarming. Surveys which can provide basic data for the elimination of the shortage of skilled workers in engineering and the increase in the number of first-year students in the above-mentioned degree programmes were started surveys among pupils, students and representatives of state authorities in 2022. Furthermore, one of the surveys was used to analyse the potential for an additional course for “sustainable mobility”.

All three surveys were conducted under the overarching aspect of consistency in order to obtain a cross-stakeholder picture. A central focus was on the topics of sustainability and digitalisation, including the extent to which sufficient preparations are made in the educational environment and which requirements are really considered necessary (also in the future) in the respective activities.

Based on these results, among others, the orientation of a planned agency for reducing the shortage of skilled workers in the road and transport sector was adjusted accordingly. The aim is to establish a coordinating institution that focuses specifically on the gap between academical education and the requirements of innovative and modern employers.

1 INTRODUCTION

The shortage of skilled engineers threatens the development and sustainable transformation of the economy and mobility in Germany.

For example, 151,300 engineering positions are unfilled (VDI, Institut der deutschen Wirtschaft. 2022) and 7,400 positions per year are projected as demographic replacement needs in construction and energy (VDI. 2022). In contrast, the number of first-year students in engineering and computer science has dropped by 15% in the last 5 years (VDI, Institut der deutschen Wirtschaft. 2022) and 53% of all students drop out of STEM studies (Acatech, Joachim Herz Stiftung. 2022). The problem is further aggravated by the demographic development, according to which the group of 15-24-year-olds has fallen below 10% for the first time.(Statistisches Bundesamt. 2022) This equals to a shortage of 8 million young people in absolute figures. In addition, the current curricula cannot keep up with the exponential growth of technological development and the associated demands from business and public administration.

The "Academy for Sustainable Highway and Traffic Engineering" was founded in March 2022 as part of a departmental research institution[1] of the German Ministry of Digital Affairs and Transport. One of its central tasks is to develop a scientific foundation for research, evaluation and quality assurance of viable, innovative and feasible concepts for recruiting, securing and qualifying skilled workers for the mobility sector.

[1] *BASt = Bundesanstalt für Straßenwesen = Federal Highway Research Institute*

In this light, this paper deals with the central question of how a sustainable skilled labour force can be secured in the mobility sector if the needs of those actually involved are queried and correlated with each other. For that purpose, three nationwide surveys with more than 1,000 participants were conducted, which are the focus of this work.

2 METHODOLOGY

2.1 The procedure

After developing a comprehensive knowledge base on the topic of skilled labour shortage, skilled labour qualification and skilled labour assurance, as well as its verification and updating through the exchange with authorities and engineering associations, empirical research was conducted between May and December 2022 among school leavers (and thus future students), students and authorities in order to gain a contribution to a more comprehensive understanding of the possible complex causes of the societal problem of skilled labour shortage in Germany.
For this purpose, a total of 864 schools were contacted, after representative federal states had been selected beforehand due to the federal structure taking into account e.g. larger cities as well as rural areas and the geographical location. This preselection was made because of the great organisational effort, for example the required approval of the respective state ministries for education, as well as participating school committees and parents` associations involved.
Initially, 35 schools with about 4,500 pupils agreed to participate, but then, also due to a peek of the Corona situation in winter 2022, the survey took place at 28 schools with a total of 2,958 participants.
With regard to the student survey, we have used to two large alliances of faculties: FTBGU[2] and FBT-BaU[3] which represent a total of 120,000 and 47,000 students respectively.
The scientific network of the federal research institutions of the Federal Highway Research Institute was used for the survey of the authorities.

One basis of our survey is based on the hypothesis that previous measures in the field of education modernisation do not lead to a significant improvement in the shortage of skilled workers in the field of engineering and in particular that

- the increase in specialised courses of study has not brought an increase in experts
- an expanded range of studies does not lead to sufficient competences of graduates
- there is a low level of satisfaction among students and employers with regard to success-oriented criteria (connectivity)

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[2] *FTBGU = **F**akultäten**t**ag **B**auingenieurwesen, **G**eodäsie und **U**mweltingenieurwesen = Faculty Association for Civil Engineering, Geodesy and Environmental Engineering e.V*

[3] *FBT-BaU =**F**ach**b**ereichs**t**ag **Ba**u- und **U**mweltingenieurwesen = German Association of Departments of Civil Engineering and Environmental Engineering at Universities of Applied Sciences (GADCEE)*

- up-to-date knowledge that needs to be constantly adapted is no longer expert knowledge for a few, but relevant and necessary for all graduates and that
- there is no target-oriented coordination between the stakeholders involved in this area

A central focus of the surveys was therefore on the extent to which sufficient preparation is provided in the educational environment of schools and universities (of applied sciences) and which requirements are actually considered necessary in the respective activities (also in the future).
For this purpose, the *Pupils'* survey (Lohbeck, Strauch, Oeser. 2022 a) mainly focused on aspects of career choice and choice of studies. The survey of the *students* (Lohbeck, Strauch, Oeser. 2022 b) mainly provided aspects of study satisfaction and evaluation of the contents as well as possible missing contents. *Public authority representatives* (Lohbeck, Strauch, Oeser. 2022 c) were asked about future needs and requirements for current and future employees, in order to identify a possible gap between the undergraduate educational content and the real requirements in the work environment.

2.2 The Data Basis

The data basis is based on responses from 691 final-year students from 28 schools throughout Germany, 244 Bachelor's and Master's students at technical universities (60%), universities (37%) and technical colleges or universities of applied sciences (3%) throughout Germany. Of these, 63% were Bachelor's students and 37% Master's students. Furthermore, 97 participants were interviewed in 25 federal research institutions, where a disproportionately high number of scientific activities are to be found. Two thirds of them have personnel responsibility..

3 RESULTS

3.1 Pupils

Asked about their educational aspirations, 54% of the participants answered that they would like to start university after graduation, 17% chose dual studies, 7% opted for vocational training, 3% for studies after vocational training. 18% said they were still unsure.

Asked in which field - irrespective of the type of education[4] - they would like to work, construction/architecture came 10th and engineering 11th out of 23 selectable fields with three possible answers. In free text fields, specific courses of study could be indicated; here, engineering received the most frequent mentions.

Asked what was particularly important to them when choosing a career, about a third of respondents said they wanted to "make a positive contribution to society". 10% said they wanted to "make a positive contribution to the environment".

[4] *In Germany, in addition to a degree course, there is the option of vocational training - usually lasting three years - which may also be offered on a dual basis, i.e. combined with higher education. Higher education studies can be taken up at a university of applied sciences or (technical) university. These can be state or private.*

As possible difficulties in choosing a course of study or a career, the pupils named "the multitude of possibilities difficult to grasp." (69%). About half of the respondents said it was "difficult to get helpful information" (54%) and "don't know what the requirements are for [their] desired profession" (47%) or "don't know if [their] school performance is sufficient for [their] desired profession (52%).

Although 20% of the young people were still undecided about what their career path should look like, it is clear that they want to make a contribution to society and the environment, but are uncertain about their skills and opportunities and feel hindered rather than supported by the (too) wide range of options.

3.2 Students

The students we surveyed indicated that they were predominantly satisfied with their degree programmes in civil engineering, transport engineering, environmental engineering, geodesy and geoinformatics, and industrial engineering.[5] However, when asked about a possible desired expansion of their degree programmes, 2/3 of the students indicated *practical relevance* and 1/3 *Socially Responsible Engineering,* among others.[6] When asked what was particularly important to them when choosing a career, 44% said they wanted *to make a positive contribution to society*; 33% wanted *to make a positive contribution to the environment*,[7] which shows a primarily content-related engagement with the field of study.
However, only just under a third feel well or very well "*prepared for [his/her] career goal*". In terms of preparation for starting a career, 51% lack "*completed internships*" and 41% lack "*specialist knowledge"*. The area of "*knowledge of the work culture at potential employers*" as the top answer is not to be taken into account here, as it does not concern possible study contents or their goals.[8]

3.3. Authorities

52% of the public authority representatives state that they will have an additional need for Bachelor engineers in the next 5 years. 92% indicate an additional need for Master engineers. Skills needed in the future were named as follows[9] : "*knowledge of new/digital techniques*" (70%), "*combination of classical engineering sciences and digitalisation*" (68%), "*social skills such as rhetoric, moderation skills etc.*" (45%), [...], "*practical experience*" (41%) and "*knowledge of sustainability / life cycle management*" (36%). Difficulties mentioned in filling positions are, in addition to too few permanent positions and too low earnings, lack of connectivity or skills of the graduates.

3.4 Summary of the results

The results of the surveys have shown that the expectations of all respondent groups are not completely fulfilled. The expectation gap between the choice of study and study is apparently not being filled at present, just as the students' expectation gap is not being filled with regard to the content of their studies and the employers' expectation gap is not being filled with regard to the competences of their future employees.

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[5] *56% of students on a scale of 1-6 rate their programme as a 2, 25% as a 3 and 10% as a 1, 1 being the best and 6 the worst in the scale.*

[6] *Up to three answers were possible here.*

[7] *Up to three answers were possible here.*

[8] *Up to three answers were possible here.*

[9] *Up to five answers were possible here.*

Pupils are mainly looking for orientation and an overview. They find the multitude of options hard to grasp, often have difficulties in obtaining helpful information and are not sure whether their school performance is sufficient.
Students miss the practical relevance and the problem-solving skills taught in their education. Soft skills such as rhetoric, communication skills, etc. are also in demand.
Public authorities need exactly these mentioned competences (practical experience, soft skills) and especially knowledge of new / digital technologies, the connection of these with the classical engineering sciences as well as knowledge in project management and also miss these among the graduates.

4 DISCUSSION

The rapid development of technology has created completely new requirements in the labour market, which none of the stakeholders - the education sector with schools and universities as well as employers - can meet with sufficient solutions. The necessary changes cannot be achieved by using existing established methods.

The establishment of further degree programmes, as they continue to be primarily basic, does not lead to the necessary teaching of special, up-to-date learning content. On the contrary, the offer of 20,951 degree courses in Germany, 3,888 of which are engineering courses (Hochschulrektorenkonferenz. 2021), leads to selection difficulties for graduating pupils. In addition, only a small number of higher education institutions have begun to teach specialist topics of the future, e.g. BIM[10] or digital twin[11]. Interdisciplinary orientations, which could provide a more precise connection of the chosen profession, are only just being established in some cases.[12]

Lifelong learning has been gaining in importance for years, but is not yet comprehensively reflected in traditional education systems, although continuing education is also anchored as a mandate of higher education institutions in German higher education laws. At the same time, the gap between the competences taught on the one hand and the competences required on the other is widening. A coordinated exchange between the stakeholders of the topic has not yet taken place sufficiently. A possible approach to the teaching of small, assessed knowledge units (microcredentials), also taking into account the third educational pathway and lifelong learning, is just emerging in the German higher education landscape.

Based on the results presented so far, the establishment of an *Academy* as coordinator of a structural network of all stakeholders is planned. Theses are: business, administration, universities, students, lateral and re-entry students and graduates as well as internationals, in order to take into account the decreasing demographic figures.
The *Academy* is to survey both current and future requirements of employers in business and administration and match these with the educational offers of the universities. The resulting gap is to be comprehensively analysed on an ongoing basis and corresponding learning content defined. These are then to be imparted in

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[10] BIM = Building Information Modeling
[11] Evaluation of various module handbooks from universities (of applied sciences) as part of the Academy's internal BIM Radar project.
[12] Cf. TUM Schools at the University of Munich, URL: https://www.tum.de/forschung/schools-forschungszentren, last accessed on 25.4.23

the third educational pathway - and in consultation with the employers - on a part-time basis. The educational providers in this concept are, on the one hand, the universities themselves, which are currently evaluating their state-mandated continuing education programmes and their engineering educational approaches, and, on the other hand, private providers and other stakeholders in the network. Microcredentials that have already been launched in the higher education sector could possibly be considered as a tool here. In addition to national and international students, lateral entrants and re-entrants should also have access in order to fill the demographic gap as far as possible.
Here experts should enable required educational content to be made available to future experts without a renewed, comprehensive additional course of study for university graduates, in order to promote willingness to continue training and to provide the labour market with qualified personnel as quickly as possible.
The *Academy* explicitly does not see itself as an educational alternative, because this is neither needed nor does it have sufficient competence in it, but rather as a coordinator in a central network that develops and analyses department-specific solutions for the field of mobility in cooperation with all stakeholders and taking into account scientific analyses.

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TOWARDS SUSTAINABILITY - FOSTERING GENDER DIMENSIONS FOR INCLUSIVENESS IN SCIENCE TECHNOLOGY ENGINEERING AND PRODUCTION (STEP) FIELDS

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ABSTRACT

Statistics from the Engineering Council of South Africa indicate that a large number of women who enter the engineering sector leave their careers in the early stages because they felt isolated and experienced discrimination in this traditionally male-dominated industry. Furthermore, research on global trends have highlighted the importance of an inclusive atmosphere as a result of the increase in the proportion of female decision-makers, racial and ethnic background differences, persons with disabilities and generation gaps with resulting different learning styles and needs. Literature also suggests that workforce diversity that maximises inclusion and minimises resistance, allows organisations to create change that fosters the human potential of their employees to the extent that diversity could be an organisation's competitive advantage.

To assist with fostering a culture of inclusion a Leadership Development Programme (LDP) was designed for early to mid-career male and female employees in Science, Technology Engineering and Production (STEP) fields by the Women in Engineering Leadership Association (WELA) at a South African university. The focus of the four-day programme included leadership, communication, diversity, being a team player,

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lean management and tools for effective problem-solving in addition to a two-day practical team exercise in a simulated working environment.

This research paper outlines the study's theoretical framework and the results from a survey and industry focus groups that guided the design of the STEP LDP. The qualitative post-workshop data from STEP LDP participants is also discussed. The results illustrated the importance and perceived value of the programme to those who had participated. Accordingly, this paper also explores and reports on the transformation in thinking following the programme participation and provides feedback and suggestions to improve the LDP. Creating an inclusive environment in the workplace is a key factor for employee growth and satisfaction as well as promoting an inclusive leadership culture. It is recommended that similar programmes are presented by other universities or within organisations to foster inclusion, thereby facilitating employee retention, in particular, women in engineering.

Keywords: Inclusion, leadership, innovation, diversity, transformation

1 BACKGROUND AND INTRODUCTION

In 2011, with support from merSETA[1], the Women in Engineering Leadership Association (WELA) was established at a South African university. WELA goals include attracting, supporting and developing women engineering students (WES) to improve retention, not only of female students, but also women already working in engineering-related fields. The underlying premise of WELA was to improve the self-efficacy of WES through developing a sense of belonging. In accordance with this mandate, a LDP was developed for WES who are WELA members. The LDP, embedded in WELA, consists of various co-curricular interventions such as workshops, short courses, seminars and factory visits. Underpinning WELA is a mentoring programme that is offered by senior WELA members to junior WELA members.

With the WELA programme established to support WES, the WELA team endeavoured to further develop their mandate by designing a series of workshops for women working in engineering-related fields. Apart from informal feedback from women in the engineering field, statistics from the Engineering Council of South Africa (ECSA) indicate that a large number of women who enter the engineering sector leave their careers in the early stages because they feel isolated and experience discrimination in this traditionally male-dominated industry (Thompson, 2015). Furthermore, research on global trends have highlighted the importance of an atmosphere of inclusiveness, which is due to the increase in the proportion of female decision-makers, different racial and ethnic backgrounds, persons with disabilities and generation gaps with different learning styles and needs (Janakiraman, 2011).

Stevens, Plaut and Sanchez-Burks (2008) suggest that workforce diversity maximises inclusion and minimises resistance and allows organisations to create change that fosters the human potential of their employees. Mor Barak (2005) further suggest that diversity could be an organisation's competitive advantage. As a result, it becomes

[1]Manufacturing Engineering and related services sector education and training authority (SETA)

evident that the need for programmes that focus on the issues of inclusion, equity and diversity is valid, warranted and important.

Ramdass (2023) noted that women offer unique advantages in the corporate environment on projects that male engineers do not. One of these being the development of solutions that benefit society. Petersen (2023) goes on further to add that women experience things through a different lens and that thinking about designs from a different perspective enhances engineering concepts.

When the WELA team researched and developed a LDP for early career employees, it was also recognised that the programme should expand its reach to include more traditionally male-dominated fields than just engineering and that it should include all genders. Hence, it was decided to name to programme "Inclusiveness for innovation in Science, Technology, Engineering and Production (STEP) fields" for early career male and female employees.

This paper provides the theoretical framework and results from industry focus groups that guided the WELA-STEP programme design. Results from feedback questionnaires illustrating the value to those who participated in the WELA-STEP programme are discussed and therefore, this paper also explores and reports on the transformation in thinking following the programme participation and provides suggestions to improve the programme.

1.1 Gender Status quo

Various factors account for the low representation of women in science and engineering. It has been proposed that environmental factors (Shull & Weiner, 2002) such as isolation, exclusion from networks and lack of role models can be major source of deterrence for women in engineering. Women engineers also experience self-doubt in traditionally male-dominated environments as they feel that are not valued as highly in their positions (Thompson, 2015).

Institutional support and "fitting in" are listed as key contributing factors to the level of job satisfaction, and research indicates that women engineers have lower job satisfaction than their male counterparts. According to Fouad, Chang, Wan and Singh (2017), these two factors can play a significant role in the reasons that women engineers leave their positions. Fajardo and Erasmus (2017) suggest that South African women feel that they are going "against the grain" when they attempt to reach more senior positions, and this perpetuates the sense of isolation and exclusion from their male counterparts. Lack of women engineering mentors is compounded by the cycle of women engineers leaving their positions early in their career. In addition, Dennehy and Dasgupta (2017) highlight that mentors do not increase belonging or confidence, but merely preserve it. In their research, mentors were described as "social vaccines" as they inoculate the mind against the negative effects of this type of bias.

There is an African proverb that states, “If you want to go fast, go alone. If you want to go far, go together”. Expanding on the work of Paulo Freire, Price and Osborne (2000:29) believe that a humanising pedagogy is “a pedagogy in which the whole person develops [not just a facet of a person] and they do so as their relationships with others evolve and enlarge”. If women feel that they are excluded and “going alone” this emphasises the problem and a humanised pedagogical approach would include both males and females and towards a common goal of developing a person a whole.

The sections below explain the theoretical foundation and development of the WELA-STEP programme.

2 THEORETICAL FOUNDATION

The WELA LDP, designed for women engineering students, was developed with the four sources of self-efficacy as its foundation because of the benefits associated with increased self-efficacy (Marra, Rodgers, Shen & Bogue, 2009). As a result, it was argued that increased self-efficacy could contribute to WELA achieving its goal of developing and retaining WES. Therefore, the WELA-STEP programme was similarly designed to encompass the sources of self-efficacy.

2.1 Self-efficacy sources

Self-efficacy is defined as a self-evaluation or self-belief of one’s competence to execute successfully a course of action necessary to reach a desired outcome or goal (Badura, 1997). The four main sources of self-efficacy are mastery experiences, social persuasion, vicarious experiences and physiological states.

Bandura (1997) defines mastery experiences as having the raw knowledge, skills and experience required to complete a task or reach a goal. Social persuasion refers to the influence of others such as the presence of social support (Hazari, Tai & Sandler, 2007). Vicarious experiences occur when some form of involvement is experienced by observing someone else or a role model engaged in a task (Hazari et al, 2007). However, the effect is dependent upon the similarity of the role model to the individual’s own abilities and circumstances. Therefore, the visibility of women and minorities in the engineering field is of critical importance to attract, retain and support women in engineering.

Marra et al (2009) propose that the impact of physiological states and anxiety, in particular, in WES is identified in the literature as stereotype threats. This refers to the potentially debilitating performance anxiety experienced by those who belong to a group for which there is a negative stereotype related to a task. WES may experience debilitating anxiety in engineering-related careers and fields of study, owing to the stereotype in these fields being predominantly male.

For the design of the WELA-STEP programme, cognisance was taken of the four sources of self-efficacy, and the potential benefits associated with developing self-efficacy in an individual. The next step in the development of the STEP programme was to obtain feedback and input from women engineers and members of industry.

2.2 Industry and working women engineers' input

WELA received several informal training and workshops requests for early to mid-career women in engineering-related fields. Discussions with several experts in the field of leadership training and development, indicated that offering a course for women only could be counter-productive and negatively influence efforts to contribute to equality in the workplace. In addition, all indications were that early to mid-career males would also welcome leadership development opportunities. Therefore, the focus of a WELA-STEP programme would be to foster leadership skills to create an environment of equality and innovation.

Obtaining feedback and input from industry involved, as a first step, the development of questionnaire for women engineers to provide input on what they thought should be included in a course that could strengthen a woman's sense of belonging, inclusion and diversity. All participants were adamant that the programme should not include the "airy fairy, women are better than men, how to dress and etiquette" items along with leadership theory. The participants felt that they rather needed "leadership in action" when dealing with different types of people and addressing issues such as how to deal with stereotyping, bias, prejudice, discrimination and micro-aggressions. Other topics highlighted included sexual harassment, diversity and cross-cultural perspectives of leadership, work/life balance and "being a change agent and pulling the masses of males with you". Self-development related topics that were raised included personal mastery, resilience, conflict management, emotional intelligence and how to connect with male colleagues and not feel left out.

Feedback indicated a definite need for a developmental programme as "women are battling to establish their worth in a male-dominated society" and that new leadership skills should be taught, aligned "to women's natural inclination for a more collaborative and community driven approach which is culturally more sensitive". One respondent stated "women lose their drive to succeed due to challenges" and felt that although coaching sessions should be included, it might be difficult to obtain support for such a programme as "most management positions in SA remain predominantly male and they won't understand why gender specific training is necessary". Finally, they also shared that most women had been trained by males and, therefore, women often looked to men as role models and that technical know-how was not the challenge of their job, but rather the bias that they experienced in the workplace.

The second step in obtaining industry input was to invite a range of industry representatives to form part of a focus group discussion. The three focus groups confirmed the input of the questionnaire participants, adding that some components of the programme should contribute to CPD points and a focus on communication in terms of dealing with different generations as well as understanding work culture and ethics and how equality can contribute to innovation. They also suggested that the programme must be fun, hands-on and allow participants to reflect. Based on the feedback from questionnaire participants and the focus groups, various themes were identified (see Table 1).

Table 1: Summary of industry participants and focus groups

THEMES	DIMENSIONS	EXECUTION- PROPOSED CONTENT
Communication: reflecting heightened awareness of self and others	– Professional – Cultural – Across generations – Presentation skills	Practical day in the simulated working environment (SWEAT) laboratory, areas of focus to include communication, teamwork, diversity, conflict management and leading teams in STEP Additional sessions on social media management and presence, presentation skills, personal portfolio
Self	– Personal wellness – Emotional intelligence – Strengths and self-worth – Resilience	Participants asked to complete assessment forms (Strengths and Weaknesses) prior to the workshop. Their results, areas of improvements and strategies for improvements to be discussed during the workshop. Additional sessions on resilience
Mentorship	– Mentorship and networking	Mentors invited to take part in a "mentor speed dating" session whereby mentors and mentees can network
Leadership: to help embrace humility through serving and being authentic	– Dealing with change – Stereotypes – 2nd generation bias – Micro-aggressions – Conflict management – Innovation – Inclusiveness – Leading STEP teams	Practical day in the SWEAT lab, areas of focus include communication, teamwork, conflict management, diversity and leading teams in STEP Additional sessions on stereotyping, bias, and micro-aggressions
Workplace/Technical	Practical problem-solving	Practical day in the SWEAT lab, areas of focus include communication, teamwork, diversity, conflict management, ethics and leading teams in STEP

		Additional sessions on: • Lean (CPD points) • Problem-solving workshop (CPD points) • Project management short learning programme (CPD points)

From Table 1, it was evident that the greatest perceived needs were what is often referred to as soft or non-technical skills. Parlamis and Monnot (2019:1) stated that "the most difficult issues in managing organisations and the people who inhabit them involve organisational and relational skills; the soft stuff is actually the hard stuff". Parlamis and Monnot (2019) list skills such as leadership, teamwork, self-awareness, managing conflict, communicating effectively and getting along is essential for individual, team and organisational success.

WELA-STEP DEVELOPMENT TEAM AND PROGRAMME IMPLEMENTATION

Considering the above proposed content, the WELA team formed a task group to develop workshop content and to design the WELA-STEP workshop series. Apart from having access to experts in the various fields to act as facilitators of the various workshops, the WELA-STEP team also has access to the Simulated Working Environment (SWEAT lab) housed within the Department of Industrial engineering. The SWEAT lab consists of a continuous production line where a product is assembled and disassembled in production teams. The SWEAT lab is ideal for the practical application of operations and production principles, teamwork, communication, and conflict management, leadership, assertive and practical problem-solving.

The WELA STEP programme was widely advertised and marketed for two years (pre-pandemic). However, during both years, the response from industry was extremely poor although sponsorship was offered for programme attendance. Owing to the poor response in terms of sign ups and limited funds, some sessions were omitted when the programme was offered. The focus of the programme was the practical SWEAT lab session, which lead to the change in participant thinking. The programme content is included below

Table 2: Outline of WELA-STEP 2-day LDP

Themes	**Portfolio**
Practical problem-solving on the SWEAT lab	Lecturer: Industrial Engineer
Teamwork embedded in shared values and solving problems	Counselling Psychologist

Diversity to enhance the appreciation of different contributions and working with people from different demographics	Success Coach: School of Engineering
Communication reflecting heightened awareness of self and others, important in teamwork and problem solving	Counselling Psychologist
Leadership that helps us to embrace our humility through serving and being authentic,	Senior Academic Development Professional: Centre for Teaching, Learning and Media

The focus of the two-day SWEAT lab workshop was teamwork, communication, leadership, conflict management and inclusion.

Four counsellors or psychologists were contracted and allocated a team of participants to whom they would provide constant feedback in terms of their development during the practical two-day WELA-STEP programme. As an additional self-development measure, participants were sent three self-report measures to complete. These are assessments whereby participants report on their perceptions, behaviours, attitudes, beliefs and feelings. The self-report measures included the *Gift Profile* (Caroline Leaf) with its focus on multiple intelligences, *Hungry, Humble and Smart* (Patrick Lencioni) with the focus on being the ideal team player and, finally, *True Colours* (Don Lowry). The aim of the self-report measures was to provide insight, for each participant, into their respective perceptions, behaviours, attitudes, beliefs and feelings. Feedback to participants included a discussion of individual results of the three self-report measures along with their experiences during the workshop to assist participants personal development and leadership skills.

3 METHODOLOGY

The sections below described the workshop procedure, data collection process and participants demographic data.

3.1 Workshop procedure

Participants were divided into teams who had to assemble and disassemble a simple product on the SWEAT lab assembly line. This task was initially done without any instructions, and the teams had to figure out the process for themselves. After an allocated time period, the facilitator would meet with the teams and discuss aspects of quality, efficiency and time, allowing participants to improve their assembly process. Over the two-day period, several new requirements were added to the product, which required participants to find better and more effective means of assembling. This scenario allowed for real-life exposure to and practice of teamwork, leadership, communication, conflict management and inclusion. Throughout the two days, theoretical sessions were presented to provide guidance and clarity as well as an opportunity to reflect on the highlighted aspects of teamwork, leadership, communication, conflict management and inclusion.

3.2 Data collection process

Participants were asked to complete a semi-structured questionnaire to provide qualitative feedback on their experiences during the workshop after they completed the two-day programme.

The focus of the workshop was teamwork, leadership, communication, conflict management and inclusion and the questionnaire focussed on gaining a deeper understanding of these issues. Qualitative data analysis aims to determine how participants make meaning of a specific event by analysis of their perceptions, attitudes, knowledge, feelings and experiences (Maree, 2019). All twenty participants completed the semi-structured questionnaire and their responses were captured on an excel spreadsheet.

When analysing qualitative data the goal is to summarise common words, phrases or themes into codes that would lead to understanding and interpretation of data (Maree, 2019). Welman, Kruger and Mitchell (2007) describe the purpose of coding as analysing and making sense of data that has been collected, therefore codes can be seen as labels that attach meaning to the raw data.

This study employed structural coding which is content-based and required identifying conceptual phrases representing the topic of enquiry. The coded segments that are similar are then collected for more detailed coding and analysis. The categories of codes are based on the topic of enquiry and are used throughout the coding process. Saldana (2009:66) proposes that this coding method is appropriate for data-gathering protocols, or exploratory investigations to gather major categories or themes. Structural coding is question-based that act as a labelling and indexing device, allowing researchers to quickly access data likely to be relevant to a particular analysis from a larger data set. Accordingly, responses were summarised and similar responses were grouped together to provide an indication of the perceptions of participants.

3.2 Participants

Participants were asked to complete feedback forms on the various sections of the two-day SWEAT lab workshop. Twenty participants representing four different racial demographics took part in the workshop thereby being truly representative of the South African nation (see Table 2).

Table 2: Age and number of participants

Age of participants	Number of participants	Gender

Up to 30 years	3 (15%)	3 female
31 – 35 years	6 (30%)	2 male 4 female
36 – 40 years	2 (10%)	2 female
41 – 50 years	7 (35%)	1 male 6 female
51 or more years	2 (10%)	2 female
Total	**20**	**20**

From Table 2, it can be seen that only 3 males participated in the course and 17 participants were female, ranging in age from their early twenties to two female participants over fifty years of age. The majority of the participants were over 35 years of age (55%), however, the results indicated that this type of developmental course is helpful to all ages. This course could be relevant to those who have never had the opportunity to attend any workshops or courses that focused on skills other than those relating to a specific job or task.

4 RESULTS

A summary of the participants' feedback is provided in Sections 4.1 to 4.8.

4.1 Perceived obstacles

The most frequently mentioned obstacles to progress were perceived to be a fear of failure or lack of confidence in oneself (35%), trust in colleagues or leadership (25%), frustration owing to working environment (20%) and not knowing oneself or what beliefs one has (20%).

As suggested by Stevens et al., (2008) workforce diversity maximises inclusion and minimises resistance, therefore providing training and workshops, especially in an environment such as the SWEAT lab allows for colleagues to better understand and therefore trust each other. This can lead to increased feelings of inclusiveness and belonging, especially for those belonging to minority groups.

4.2 Core personal value

For 55% of the participants, integrity was held to be the primary personal value. Three other values were mentioned by 20% of the participants, namely, strong work ethic, honesty/ethics and excellence/professionalism. With these values it is vital that participants are provided with the tools required to be confident in their roles and have a sense of belonging in their work environments. This contributes to employees living their values to make a difference to the success of the position they are in and the company, in the long run. Belonging is a feeling of security and support when there is acceptance and inclusion for employees, when employees feel they belong at work their performance and personal lives improve (www.diversity.cornell.edu).

4.3 Ease or challenges working in teams

There were a number of aspects that were believed to make working with someone easier. These included everyone understanding what their roles are (25%) and 20% identified clear communication or instructions. Some identified that if people were easy to work with, then the team worked well and helped each other. Twenty percent indicated that it was not easy if team members were difficult, did not communicate or were bossy. Therefore, it is vital that participants developed the self-confidence to address issues in a team environment and also communicate effectively with other members within the team both on a professional level and personal level (should issues arrive).

4.4 Self-discovery regarding problem-solving

Forty percent of participants believed that they were good at problem-solving and were able to "contribute at a high level". Discussing the task before starting it and trying to think of smarter and more innovative ways to carry out the task were mentioned by 20% of the participants as an effective way of dealing with a problem. Therefore, as mentioned, communication plays a vital role in problem solving and various stages of the SWEAT line workshop allows for an opportunity to practice this. Being heard and respected as a team member and making a valid contribution in a small team, such within the WELA-STEP programme, can encourage women and lead to greater feelings of self-efficacy and therefore feelings of belonging and inclusion.

4.5 Diversity in the workplace

Diversity was considered essential in the workplace (35%) as it allowed the strengths and differences of all to be used (30%). There was only one negative comment about the impact of diversity in the workplace, namely, "race is a negative role towards me in terms of the ratio of the cultural mix in the work setting". Two delegates felt it was not an issue at all and did not have any impact. The session on diversity was considered informative owing to hearing other participant's views and ideas (25%), being accepting of others' differences and neurodiversity indicating that diversities were not always obvious (25%).

If organisations embark on developmental programmes for men and women in traditionally male dominated environments it can lead to breaking down stereotypes and women feeling that they "are going against the grain" (Fajardo and Erasmus, 2017) and eliminated women's sense of isolation and exclusion from their male counterparts.

4.6 Leadership in workplace

Twenty-five percent of participants were of the opinion that leadership should be consultative and that they should consult with their team members before making big decisions. Other comments related to the requirement that leaders be more open and communicate more with the staff (20%) and that not all leaders were good leaders

(15%). Three participants did not appear to be concerned about leadership in their organisation but preferred to focus on themselves.

Forty-five percent of participants realised that they still had a lot learn and there was still room for improvement before taking on the role of a leader. Twenty-five percent of participants believed that they had the potential to be a leader. Pocztowski (2003: 214) describes leadership as a process of influencing others so that they voluntarily engage in achieving an organisations goals. Parlamis and Monnot (2019:1) suggested that “the soft stuff is the hard stuff” . It is often not regarded by organisations as critical training, however, it can be seen that “soft skills’ training is critical for organisational success and for creating understanding for issues o equality and diversity, and creating a sense of inclusion and belonging.

4.7 Shift in thinking

The shift in thinking came about with the realisation of the importance of knowing and understanding oneself (35%), followed by understanding the value of the difference between thinking about something and actually doing it (20%).

Many of the responses (35%) reflected the uncertainty that attendees felt in addressing their future. Sixty percent of participants recognised that they needed a significant shift in their communication in their personal lives and in the workplace. Forty percent mentioned that their communication needed to be more specific and concise and that the communicator should ensure that all had the same level of understanding. In addition, communication should always be positive, respectful, friendly and polite (25%). It was also mentioned that it must be understood that different people communicate in different ways and that one should not “jump to conclusions” just because someone communicated differently. Skills such as leadership, teamwork, self-awareness, managing conflict, communicating effectively and getting along is essential for individual, team and organisational success (Parlamis and Monnot, 2019). Therefore, the WELA-STEP workshop can make a contribution towards individual, team and organisational success. Focussing on changing mind-sets can lead to a friendlier and more inclusive environment for women in the field.

5 CONCLUSION AND RECOMMENDATIONS

It became evident that participants experienced a shift in thinking regarding their communication practises. This was triggered by the practical exercises, self-reflection and workshop sessions. In addition, it appeared that a large number of participants recognised that they required more self-development to become better future leaders.

Based on the responses from the WELA-STEP workshop participants, it was clear that development in aspects of leadership, communication, diversity were necessary for all employees. It was acknowledged that the sample on which the paper is based consisted of a small number of participants, which should be further investigated. The workshop was designed based on the needs identified by industry members, yet some sessions had to be cancelled owing to a lack of interest. The question that could be asked is whether industry really needed and valued developmental programmes for early to mid-career employees, whether they were concerned with retaining women in scarce skills areas, whether they felt it was the responsibility of individuals to develop these skills themselves, or whether it was purely a matter of time, resources and being output-orientated. These questions need to be explored in a future study as they are pertinent for creating an inclusive environment in the workplace, which is a key factor in employee growth and satisfaction contributing to retention of, in particular, women engineers.

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VALIDITY OF STUDENT PROFESSIONAL PRACTICE COMPETENCY CLAIMS

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ABSTRACT

The University of Sydney has introduced a program of engaging engineering students throughout their degree program in diverse forms of self-selected exposure to, and engagement with, professional practice. To gain recognition of completed activities students are required to submit "claims" that include identification of the core competencies that were developed and demonstrated during the activity, along with a detailed reflection on their learning. Given that the claims are highly individualised and often unsupervised, assessment is predominantly limited to evaluation of the reflections along with evidence of the activity. A key question in the program relates to the validity of the assertions made by student regarding the competencies that have been demonstrated. In this paper we report on an analysis that compares student claims regarding competencies that were developed with the language contained within their reflections, and the extent to which those reflections focused on the competencies specifically being claimed. The results suggest that for claims related to some competencies, such as team skills, the student reflections do indeed tend to include a stronger focus on that competency. Conversely, for other competencies, such as understanding of the underpinning sciences and engineering fundamentals, the reflections are much less clearly connected to the competency. This may be the result of greater diversity of understanding, but we also consider the possibility that it may relate to less clarity by students regarding the language used in reflecting on these competencies, and the implications of this for the development of their understanding.

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1 INTRODUCTION

1.1 General Context

A long-standing consideration within Engineering degree programs has been the role of student connections to professional practice. A key argument (particularly in many accreditation processes) is that exposure to, or engagement with, professional practice as a core element of degree programs is an important mechanism for developing professional competencies, and for integrating these competencies with the more technical capabilities that are developed.

Opportunities to strengthen educational outcomes associated with exposure to professional practice, as well as growing challenges in obtaining high quality internship experiences for students has led to a growing interest in alternative approaches to providing students with exposure to professional practice. In 2018, The University of Sydney introduced a novel professional engagement program for all new undergraduate engineering students. Throughout their degree program students are required to select and complete a wide range of both in-curricula and extra-curricular activities, with these activities scaffolded through a series of workshops. For each completed activity they must submit a “claim” that involves a detailed reflection as well as report on the professional competencies that they demonstrated. The result is a very large collection of student activity reflections (currently exceeding 12,200 reflections on extra-curricular activities, averaging approximately 400 words per reflection). These reflections provide a rich source of information on student reactions to, and understanding of, the nature of practice. The students also have access to a reporting dashboard (see Figure 1) that provides them with a summary of the number of hours of activities they have successfully completed as well as the balance across different competencies.

It is important that understand whether student claims regarding individual competencies are likely to be valid. A first step in exploring this question of validity is to look at the extent to which the student reflections are focused on the competency being claimed. In this paper we therefore report an analysis of student reflections. We identify the various engineering competencies that are being considered and how these relate to the specific claims being made by students in terms of the competencies that were the focus of their activities.

1.2 Exposure to Professional Practice

Numerous reviews into Engineering education have recognised the need for engineering students to develop broader professional skills in addition to technical skills development (e.g. Graham 2012; National Academy of Engineering 2004). Historically, one of the key approaches used in supporting the development of these broader skills, as well as integrating the various competencies into a holistic whole, has been the use of exposure to, or indeed engagement with, professional practice during undergraduate studies (Ryan et al. 1996). This recognition of the value of engagement with professional practice is so deeply recognised that it has become embedded in many accreditation frameworks (ABET 2011; Engineers Australia 2013; UK Engineering Council 2014).

A key challenge in managing exposure to practice programs has been the question of how student activities can be assessed. A range of characteristics of these programs make assessment somewhat challenging, for example: the diversity of the experiences and hence outcomes; the individual nature of student involvement; and the qualitative character of many of the competencies that form the focus of development. Due to these challenges it is common to rely on student self-assessment of their outcomes – requiring students to reflect upon their experiences and evaluate their learning outcomes.

1.3 Student Self-Assessment

There is a considerable body of research that explores both reliability (i.e. consistency across time, student, activity etc.) and validity (i.e. are we measuring what we believe we are) of student self-assessment. Cassidy (2007) explores self-assessment in the particular context of inexperienced students (which will often be the case in engineering programs), arguing that "findings suggest that while self-

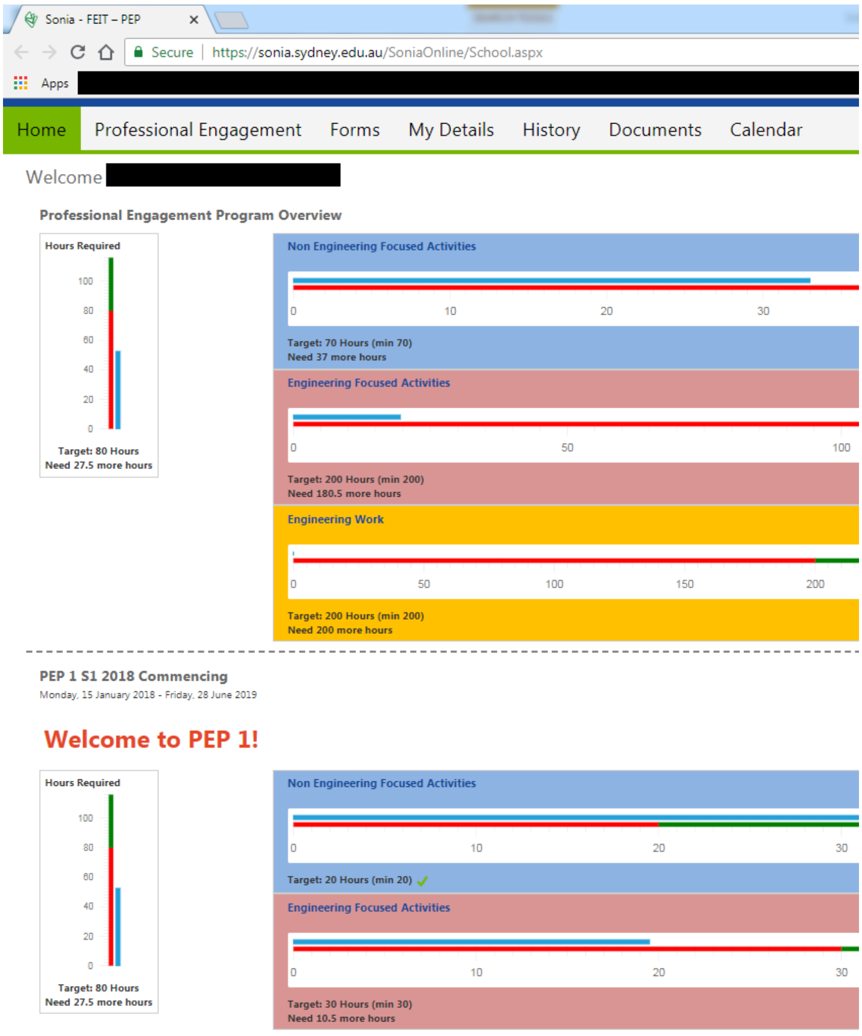

Figure 1: Professional Engagement Program: Student Dashboard

assessment skill undoubtedly develop, becoming more effective during students' academic career, inexperienced students do have the capacity for self-evaluation". It is noted in this study however that this is a significant minority of students for whom self-assessment is problematic. Another interesting study in this area (Baxter & Norman 2011) notes that there is significant doubt about students' self-assessment ability but makes a useful distinction between perception of self-assessment capability and actual reliability of self-assessment.

Whilst the above studies focused in specific (often technical) skills, another study (Chan et al. 2017) focused on students' perceptions of competency in generic skills and in the engineering domain. Essentially this study was aiming to understand students' motivations to develop generic skills by investigating their perceived level of self-competence. Unfortunately, this study was relatively narrow and only considered students perceptions of their competence, and not how this related to actual competence. It is useful however insofar as it suggests student typically perceive that their technical competence is lower than their generic skills!

Other similar studies (Donnon et al. 2013; Falchikov & Boud 1989; Ross 2006) continue the pattern that the level of both reliability and validity of students' self-assessment tends to vary significantly depending upon a wide range of factors: student experience; level of knowledge; domain of knowledge; discipline area; and especially the level of training in how to undertake a self-assessment.

One relatively common pattern in the literature, particularly regarding support for effective self-assessment, is the use of student reflection. This is particularly significant in the context of encouraging a more critical analysis by the students, and hence an increase in validity of the outcomes. Student reflection is, however, only likely to be most effective is the reflections relate to the competencies that are the focus of self-assessment. It is this issue that is the focus of this paper: exploring the extent to which students undertaking self-assessments of selected competencies are reflecting on aspects that do relate to those competencies.

The Professional Engagement Program (PEP) at the University of Sydney provides a useful source of data in exploring this question. This is especially true given two key characteristics of PEP: (1) the deep integration of both student reflections and self-identification of competencies that have been developed; and (2) the very substantial diversity of student professional engagement activities that are undertaken, and hence the opportunity for developing very diverse competencies.

2 METHODOLOGY

The Professional Engagement Program commenced in the 2018 academic year. Subsequently, students submitted numerous activity claims. Certain types of claims required student to both submit a reflection on the activity and to identify up to three competencies that were demonstrated through that activity. A data extract was taken from the online claim system and the data was then cleaned (to remove claims without reflections, that had not yet been assessed, or had been assessed as inadequate). The identified competencies were then matched back to the reflections (these are stored separately in the system) resulting in N=2,368 pairs of demonstrated competency and reflection.

The reflections contained an average of 411 words per reflection in each claim. (This resulted in close to a million words of reflection across the claims being considered). The following is an extract from a typical reflection:

> *"I undertook this activity as I thought it would be an excellent opportunity to develop my skills in engineering whilst also enhancing my abilities to work with a team of strangers […] Initially, being one of the more junior members of the group, I felt apprehensive engaging in group discussions and planning as I was unsure of my ability to actively contribute something useful. However, as I became more comfortable with my group members and our task I began to open up and suggest ideas […] one thing that I learnt the most from this experience was the importance of voicing opinions during the design, planning and construction of a project".*

These reflections were then imported into NVivo and a thematic coding was carried out. Each reflection was coded against each of the sixteen Engineers Australia Stage 1 competencies (Engineers Australia 2013) – see Table 1. A fully manual thematic coding was impractical given the volume of content, but the nature of the content (i.e. reflections of practical experiences that followed relatively similar patterns of activity, with reflections structured against a common professional competency framework) made an auto-coding approach feasible (see (Guest et al. 2012) for a discussion of this can be carried out). Each reflection was auto-coded by searching for the existence of key verbs associated with each competency. The key verbs were drawn from descriptions of the competencies within a range of professional frameworks. A random sample of the coded reflections (N=50) was then assessed to ensure that there were no systematic errors being introduced.

Table 1. Summary of Engineers Australia Stage 1 competencies. See (Engineers Australia, 2013) for full details.

1. KNOWLEDGE AND SKILL BASE	
1.1.	**Comprehensive, theory based understanding** of the underpinning natural and physical sciences …
1.2.	**Conceptual understanding** of underpinning mathematics and information sciences.
1.3.	**In-depth understanding** of specialist bodies of knowledge within the engineering discipline.
1.4.	**Discernment** of knowledge development and research directions within the engineering discipline.
1.5.	**Knowledge** of engineering design practice and contextual factors impacting the engineering discipline.
1.6.	**Understanding** of the scope, etc. of sustainable engineering practice in the specific discipline.
2. ENGINEERING APPLICATION ABILITY	
2.1.	**Application** of established engineering methods to complex engineering problem solving.
2.2.	**Fluent application** of engineering techniques, tools and resources.
2.3.	**Application** of systematic engineering synthesis and design processes.
2.4.	**Application** of systematic approaches to the conduct and management of engineering projects.
3. PROFESSIONAL AND PERSONAL ATTRIBUTES	
3.1.	**Ethical** conduct and professional accountability.
3.2.	**Effective** oral and written communication in professional and lay domains.
3.3.	**Creative**, innovative and pro-active demeanour.
3.4.	**Professional** use and management of information.
3.5.	**Orderly** management of self, and professional conduct.
3.6.	**Effective** team membership and team leadership.

For each unique valid reflection, we calculated the total number of words in the reflection, along with the number of occurrences of the verbs associated with each competency. Dividing the latter into the former provided a “verb density” for each competency in each reflection. Given that these densities would depend upon the overall choice of verbs used, a direct comparison between densities for each competency was not appropriate. Instead the densities were then converted into z-scores for that competency.

For example, consider competency 1.5 (knowledge of engineering design). This had an average density of related words of 0.54% of all words, and a standard deviation of 0.81%. An example claim with a lower than average proportion of words related to knowledge of design had a word density of 0.27%, and hence a z-score of -0.37. Conversely, a different claim had a higher proportion with a word density of 1.76% and a z-score of +1.45.

For each claim, the competencies were put in order from highest to lowest z-score. This meant that if a given reflection discussed a particular competency much more than the average for that competency, then it would have a high z-score for that competency and so would be rated highly and vice versa. These ratings were then compiled for all competencies, and the results collated. This approach allowed us to explore the extent to which students who asserted that a particular activity allowed them develop a given competency then actively reflected upon that competency within their associated reflections. Further, we could compare these patterns across different competencies, and especially to see whether any patterns emerged.

3 RESULTS

Table 2 shows the resultant average z-scores for the verbs associated with each competency in the reflections. Each row represents the set of activity claims where the students have asserted that they developed each specified competency. For example, the final row represents all the claims where the students said they developed competency 3.6 (effective team membership and team leadership). In this row you can see that on average the associated reflections had a z-score of 1.03 for verbs associated with that competency– i.e. just over one-standard deviation above the average for all reflections – suggesting that, on average, students who claimed that they developed team skills during the activity, did indeed discuss team skills in their reflections significantly more than average. You can also see other insights from this data. For example, students who claimed that they developed competency 2.3 (application of systematic synthesis and design processes) also discussed teamwork (competency 3.6) somewhat more than average, with a z-score of 0.54.

Analysing this data, and in particular looking at the outliers, allows several quite interesting insights to emerge. Firstly, considering Table 2, we can see that the claims associated with every one of the competencies contained reflections with an above average density of verbs related to the competency being claimed. This suggests that on average students are indeed making an attempt to reflect on the

Table 2. Average z-score for verbs associated with each competency in student reflections (with outliers shown highlighted)

		Competency referred to in reflections															
	Comp	1.1z	1.2z	1.3z	1.4z	1.5z	1.6z	2.1z	2.2z	2.3z	2.4z	3.1z	3.2z	3.3z	3.4z	3.5z	3.6z
Competency claimed	1.1	0.31	0.31	0.72	0.29	0.08	0.38	-0.15	0.23	0.17	-0.18	0.36	-0.22	-0.14	0.23	-0.09	-0.37
	1.2	0.38	1.01	-0.11	0.13	-0.11	0.99	0.30	0.02	-0.12	-0.17	-0.06	-0.28	0.24	0.64	0.32	-0.30
	1.3	0.37	0.16	0.56	0.08	0.08	0.02	-0.08	0.22	0.00	-0.18	-0.11	-0.14	-0.02	0.03	0.09	-0.29
	1.4	-0.15	-0.21	0.99	0.68	0.06	-0.12	-0.24	-0.18	0.04	-0.13	-0.17	0.05	-0.20	0.13	-0.20	-0.35
	1.5	0.02	0.08	0.08	0.20	1.01	0.05	0.22	0.40	0.94	0.18	-0.08	-0.15	0.02	-0.02	-0.11	-0.08
	1.6	0.01	-0.14	0.43	0.27	0.63	1.00	0.04	0.16	0.18	0.03	0.06	-0.08	0.17	0.04	-0.11	-0.27
	2.1	0.19	-0.09	0.09	0.05	0.31	0.32	1.27	0.24	0.76	0.25	-0.13	-0.40	0.39	-0.07	-0.13	-0.07
	2.2	-0.06	0.59	0.05	-0.02	0.24	0.53	0.00	0.55	0.17	0.14	-0.10	-0.27	-0.02	0.05	-0.02	-0.24
	2.3	-0.11	0.15	-0.24	0.23	0.95	0.17	0.76	0.57	1.17	0.43	-0.09	0.01	-0.04	-0.36	-0.19	0.54
	2.4	0.08	-0.19	0.01	-0.08	0.37	-0.05	0.00	0.03	0.23	1.56	0.03	-0.08	-0.16	-0.18	-0.09	0.52
	3.1	0.12	-0.18	-0.15	-0.02	-0.01	0.70	-0.27	-0.01	-0.27	-0.19	1.37	-0.16	-0.06	-0.01	0.08	-0.23
	3.2	-0.12	-0.19	-0.19	-0.03	-0.23	-0.23	-0.15	-0.14	-0.26	-0.27	-0.07	0.75	-0.14	0.03	-0.05	-0.23
	3.3	-0.02	-0.15	0.09	-0.09	-0.14	-0.26	0.02	-0.07	-0.03	-0.20	-0.08	-0.35	0.19	-0.12	0.02	-0.26
	3.4	0.12	0.15	-0.03	0.28	-0.26	-0.05	-0.15	0.12	-0.24	-0.08	-0.19	-0.04	-0.17	0.92	-0.06	-0.37
	3.5	-0.17	-0.28	-0.23	-0.04	-0.28	-0.19	-0.10	-0.19	-0.31	0.00	-0.05	-0.13	-0.08	-0.10	0.32	-0.26
	3.6	-0.04	-0.23	-0.25	-0.28	-0.23	-0.22	-0.03	-0.14	-0.25	0.01	-0.04	0.01	-0.06	-0.23	-0.07	1.03

competencies that they are claiming. It is interesting to note though that the average levels did vary significantly. For example, for claims associated with competency 2.4 (conduct and management of projects), the reflections had a z-score for that competency of +1.56, suggesting a strong relevant focus in the reflections. Conversely, competency 3.3 (creative and pro-active demeanour) had reflections with a z-score for that competency of only +0.19, suggesting that the focus was only a little above the average.

Drilling further into the details of the analysis, we also found that the extent of variation between individual claims depended on the specific competency being claimed. The competencies which had the highest proportion of claims with reflections focused on the competency included: 1.4 (knowledge development), 2.1 (complex problem solving), 2.4 (management of projects), 3.2 (communication) and 3.6 (teamwork). Conversely, the competencies which had the lowest proportion of claims with relevant reflections included: 1.1 (underpinning sciences), 1.2 (mathematics), 2.2 (application of tools and techniques), 3.1 (ethical conduct) and 3.3 (creative and pro-active demeanour).

Comparing these two sets of competencies reveals a possible explanation. The first set may tend to be associated with elements where the students are likely to have a solid grasp of the language associated with the competency. The latter set may relate to competencies where the students lack a grasp of the language associated that competency – making it more difficult for them to construct effective reflections. For example, whilst they are likely to have significant exposure to the language of communication and teamwork, the same may not be true of the language of ethical conduct. If this observation is indeed correct, then this suggests that there may well be a problematic cycle at play: students don't have the language to reflect effectively on selected competencies, and hence they choose not to, and so their depth of understanding in that area remains unsupported by effective reflection.

Another interesting pattern can be seen with competency 3.5 (self-management and professional conduct). With this competency, just over 50% of the claims had reflections with a z-score ranked 1-4, suggesting that these students did discuss this competency in some detail. Somewhat surprisingly however there is 21% of the claims where the reflections had very little or no use of verbs associated with that competency (possibly because of a lack of understanding of the intent of this particular competency). A similar pattern, though not quite as pronounced, also occurs for competency 3.3 (creative and pro-active demeanour). One possible conclusion from this data is that there are certain competencies where the level of understanding is much more diverse, and so more care needs to be taken to ensure that certain students are not left behind.

And one final observation can be made from the data. There are interesting patterns of coupling between different competencies. For example, students who were claiming that their activity developed competency 2.3 (application of systematic synthesis and design processes) also had a higher than average likelihood of discussing 1.5 (knowledge of design practice). The reverse is also true. This particular coupling is not surprising given the inherent relationship between these two competencies. There are other couplings for which the reason is less obvious. For example, students who claimed that their activity developed competency 1.2 (mathematics) also had a higher than average likelihood of discussing 1.6 (sustainable practice), though interestingly the reverse is not true. The explanation for this is unclear but may relate to students struggling to reflect effectively upon their conceptual mathematics knowledge, and hence revert to reflecting upon much broader knowledge bases – and competency 1.6 may be somewhat of a catch-all.

4 SUMMARY AND ACKNOWLEDGMENTS

The findings described above have some important implications for educators. Firstly, as noted, it is likely that students are more likely to reflect effectively on the development of a claimed competency when they have clearly understood language skills related to that competency. This suggests that it is important not only to develop specific competencies, but to consider students' development of the language used to describe those competencies.

Another important implication arises from the evidence that there is much more significant variation in the nature of student reflections with regard to some competencies than with others. The greatest variations appeared to occur with competencies connected to student agency – e.g. 3.5 (self-management and professional conduct) and 3.3 (creative and pro-active demeanour). A key lesson from this is that to promote the development of these competencies, we should first address issues of student diversity and agency.

And finally, these results support the importance of providing guidance to students overall on reflective writing and how this relates to understanding their strengths with regard to different competencies. An interesting exercise worth exploring may be to provide students with a list of key verbs related to each competency and ask them to use them in the writing. Further work will also more explicitly focus on analysing the outliers identified in Table 2.

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STUDENTS' VIEWS OF TAUGHT PROFESSIONAL COMPETENCIES: INVESTIGATING THE IMPACT OF PREVIOUS WORK EXPERIENCE

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ABSTRACT

The ability of Engineering graduates to function as successful professionals depends not only on technical disciplinary knowledge but also on a wide range of professional competencies. Students' reactions to the teaching and assessment of these competencies are often negative. An ongoing study by the authors has been exploring the nature of these reactions and in particular, the various factors that contribute to students' views on the teaching of professional competencies. A preliminary factor analysis showed that students' level of professional experience was a key factor in shaping variations in their views. In this paper, we explore this issue in more depth. For example, when asked on the pair of survey questions "do you agree or disagree that each competency type [professional / technical] should be a core component of your Engineering degree program", the impact of increasing professional experience on the average response was only marginally greater for professional competencies than for technical competencies. In contrast to this, when asked the pair of questions "for each competency type [professional / technical] indicate whether it is easier to learn it at University or at work", the analysis of the responses shows that as the level of experience increases, there is a small shift for technical competencies towards being taught at University, whereas for professional competencies, there is a significantly greater shift towards being taught in work environments. We explore these, and other related findings, and consider their implications for the design and delivery of engineering degree programs.

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1 INTRODUCTION

1.1 General Context

It has long been recognised that the ability of new Engineering graduates to function as successful professionals depends not only on their technical knowledge, but also on a wide range of “professional competencies” (Scott and Yates 2002). Consequently, most Engineering degree programs have at least some focus on the teaching of these competencies. Indeed, the Washington Accord (and hence the various national accrediting bodies) explicitly include related learning requirements (e.g. ABET 2011; Engineers Australia 2018; UK Engineering Council 2014). Beyond just a need for specific professional competencies, there is also a growing recognition that graduates need to integrate their technical expertise and their broader professional skills development into a coherent integrated whole (Crosthwaite 2019; Passow and Passow 2017). This has been acknowledged in various reviews of Engineering Education (e.g. Graham 2012; King 2008) and is also reflected in the emergence of a range of “integrated engineering” programs into engineering curricula (Bates et al 2022).

1.2 Professional Experience

Possibly the most common approach to developing an integrated professional capability within engineering programmes (across a wide range of disciplines) has been the use of internships, practicums, or industry placements (Ryan, Toohey and Hughes 1996). This is potentially related to both accreditation requirements and the long history of related research into the impact of exposure to, or engagement with, professional practice. In terms of the former, accreditation bodies often suggest (either explicitly or implicitly) that time spent directly in industry settings are a preferred approach. For example, the Engineers Australia (EA) accreditation criteria refer specifically to “workplace placements” (without making it mandatory):

> *“Student engineers need in addition to knowledge, formative experiences of how engineering professionals: a) Think, work and continually learn … EPP must culminate in a set of meaningful experiences that result in the habituation of professional working styles. … The outcome should be that student engineers are able to aggregate different experiences towards their portfolio of EPP. … The overall EPP experiences should enhance a graduate’s capacity to move with ease into a professional workplace.” (Engineers Australia 2018, 17-18)*

There is also significant research that explores the value of explicit industry engagement. In many cases, this goes further and argues that full development of professional expertise can only be developed in “practice” and hence academic programs on their own will not be sufficient (Dall'alba and Sandberg, 1996; Lenihan et al 2020).

1.3 Effects of Professional Experience on Student Views

There is a relatively large body of research (e.g. Martin et al 2005) into the impact of exposure to professional practice on student development of competencies. One significant gap relates to understanding the effect of this exposure on students’ *views* regarding the development of different competencies. There is significant evidence that suggests that students can react negatively to this development (Brookfield

2017). If students do react negatively, then it can lead to reduced student motivation and engagement, and hence inhibit achievement of the intended outcomes.
In designing educational activities related to the development of professional competencies, academic staff and programme leaders often make assumptions regarding why students might respond in certain ways. These assumptions can then drive (either explicitly or implicitly) our pedagogic approaches. As an example, if we were to assume that students largely believe that professional skills are important, but that they are better learnt in practice settings, then we might work to ensure that our educational approaches, beyond the inclusion of industrial placements, prioritise authenticity in practice activities.
In responding to these issues, the authors have been undertaking a large scale study exploring factors that influence student views on the learning of professional competencies. This research showed that students' level of professional experience had a significant impact on students reactions. It is therefore useful to analyse this specific driver in more depth. If we can understand the impact of professional experience in more detail, then we can potentially use this understanding to shape when and how we approach the development of these competencies.
Given the above observations, in this paper we explore the following question: to what extent do students' level of professional experience affect their views on the learning of professional vs technical competencies?

2 METHODOLOGY

A large scale survey of undergraduate and postgraduate students, and alumni, was carried out at The University of Sydney and University College London. The design of the survey was informed by existing literature on student reactions to professional practice, as well as an analysis of student feedback and reflections on the existing programs at the lead author's University.
Questions were framed around a set of 4 professional competencies and 4 technical competencies:

- Technical competencies
  - o Understanding of underlying mathematics and science foundations
  - o Technical knowledge associated with your particular field of engineering
  - o Ability to clearly define and creatively solve open-ended problems
  - o Ability to apply a systematic design approach addressing multiple perspectives
- Profession competencies
  - o Understanding of how other disciplines (including business, law and social sciences) intersect with engineering
  - o Skills in communicating in both technical/non-technical and both written/verbal forms
  - o Ability to work effectively as a member of a team
  - o An understanding of professional/ethical obligations and an ability to manage your own development

Specific question domains included seeking students' views on each of the following, with respect to these competencies:

- The quality of teaching of each competency
- The respondents’ degree of interest in each competency
- The degree of difficulty in becoming capable in each competency
- Whether each competency should be taught within degree programs
- The respondents’ perceived level of capability (both now, and at earlier stages)
- The importance of each competency at varying career stages
- The extent to which each competency is underpinned by rigorous theory
- Where it is easier to learn (academia vs industry) each competency

An initial survey was designed and then pilot tested with an initial cohort of 30 respondents. These respondents were then interviewed to assess their interpretation of the questions (assessing the construct validity). The survey was refined based on this evaluation, before being disseminated to students. The participants were recruited through broadcast announcements on student forums. Participation was anonymous and voluntary.

The resultant survey data was then analysed using an exploratory factor analysis (Costello and Osborne, 2005) to attempt to identify the underlying factors that were most significant in accounting for the variations in students’ responses. (The detailed results of this analysis are currently being prepared for journal submission elsewhere). The exploratory factor analysis identified a set of dominant factors, but also suggested several patterns that warranted deeper investigation. One key area related to variations in student responses based on their level of previous professional experience.

3 RESULTS

3.1 Preliminary Analysis

After removing responses that contained incomplete data (e.g. where the survey was abandoned whilst incomplete) or erroneous data (e.g. where a respondent had clearly responded with the lowest response to all questions), this left N=339 responses. Demographic data on these respondents is given in Table 1.

Table 1. Demographic data on survey respondents.

	20 or younger	**21 to 25**	**26 or older**
Age	55.8%	38.4%	5.9%

	Female	**Male**	**Other/rather not say**
Gender	40.7%	58.4%	0.9%

	None	**<1 month**	**1 month to <3 months**	**3 months to <12 months**	**1 year to <3 years**	**3 years or more**
Level of (cumulative) exmployment experience (any type of employment)	14.8%	15.6%	17.1%	26.0%	17.4%	9.1%
Level of (cumulative) exmployment experience (professional employment)	69.0%	11.8%	5.9%	7.4%	1.5%	4.4%

In terms of participants' views, they were asked a series of questions about both technical and professional competencies, as follows:

Q1. Please indicate whether you agree or disagree that each competency type should be a core component of your Engineering degree program. (Likert scale: 1=Strongly disagree, 5=Strongly agree)

Q2: Indicate for each competency whether it is easier to learn it at University or at work. (Likert scale: 1 = Much easier at university; 2 = A little easier at university; 3 = About the same; 4 = A little easier at work; 5 = Much easier at work).

Q3: Theory vs practice: Put the list of 8 competencies given below into order starting at the top with the one that most needs an understanding of formal theory (rating=1), and ending at the bottom with the one needs the least amount of formal theory (rating=8).

Table 2 provides a summary of the results for these questions.

Table 2. Student views on professional vs technical competencies, and how this varies with increasing levels of professional practice.

*Q1: * Average score on likert scale (1=strongly disagree to 5=strongly agree);*
*Q2: ** Average score on likert scale (1=much easier at Univ to 5=much easier at work)*
*Q3: *** Average rank of competencies (1=most needs theory to 8=least needs theory)*

	Level of Professional experience					
	<1 month (N=274)	1-12 months (N=45)	>12 months (N=20)	<1 month	1-12 months	>12 months
	Professional competencies			**Technical competencies**		
Q1 * (should be core in degree)	4.28	4.49	4.50	4.53	4.71	4.70
Q2 ** (where easier to learn)	3.34	3.64	3.90	2.50	2.51	2.24
Q3 *** (does it require theory)	5.51	5.51	5.87	3.49	3.49	3.14

3.2 Students' views on whether technical and professional competencies should be core in the degree?

Looking at Q1 in Table 2, these results suggest that all students have a slightly stronger belief that the development of technical competencies should be a core component of their degree, than for professional competencies. This result is not particularly surprising. Similarly, this result shows that students with a greater level of professional experience tend to see greater importance of including both technical and professional competencies in their degree. Again, this may not be particularly surprising, and can probably be attributed to an increasing awareness by students of the need for various skills that arise from greater experience with professional practice. It is worth noting though that the level of professional experience required to change students' views is relatively low (1-2 months), and additional experience (>12 months) doesn't appear to lead to further change.

What is possibly more surprising is that the increase in the ratings are relatively similar for the delta between <1 month experience, and >12 months experience: 0.22 for professional competencies (statistically significant at p=0.024 using an unpaired t-test). vs 0.17 for technical competencies (p=0.038).

An argument that is often made is that exposure to professional practice will likely have a significant benefit in terms of assisting students in understanding the importance of professional competencies within their practice. These results suggest this impact may not be as significant as expected, and may not be substantially different from the impact on their understanding of the importance of technical competencies.

3.3 Students' views on where is it easier to learn technical vs professional competencies?

Considering Q2 in Table 2, the results for this question show a much more significant difference between professional and technical competencies. As the level of experience increases, there is a small shift for technical competencies towards being easier to be taught at University (though this is not statistically significant, p=0.24), whereas for professional competencies, there is a much greater shift towards believing that they are easier to learn within work environments (this shift is statistically significant, p=0.0073) . It is also worth noting that this shift occurs much more as the level of professional work experience increases (especially beyond the 1 year level). Of the 20 respondents with more than 12 months of professional experience, only 1 of them rated technical competencies as being easier to learn in a work environment, whereas 18 respondents rated professional competencies as being easier to learn in the workplace. It would be informative in a future study to investigate if the in-depth and fundamental learning of technical competencies at university as opposed to the more practical application of technical competencies often supported through the use of software tools in the workforce contributes to the small shift in technical competencies being easier to learn at university.

Table 3. Student views on where it is easier to learn professional and technical competencies
Average score on likert scale (1=much easier at Univ to 5=much easier at work)

	Level of professional experience		
Professional Competencies	**<1 month**	**1-12 months**	**>12 months**
Interdisciplinary Connections	3.60	4.04	4.20
Communications	3.02	3.40	3.55
Teamwork	3.26	3.42	3.85
Professional / Ethical Development	3.48	3.71	4.00
Technical Competencies	**<1 month**	**1-12 months**	**>12 months**
Underlying maths and science foundations	1.58	1.27	1.30
Technical eng sub-discipline knowledge	2.32	2.04	2.20
Define and solve open-ended problems	3.07	3.04	3.10
Apply a systematic design approach	3.09	2.93	3.05

Another interesting implication of the above results is that it suggests that greater exposure to professional practice might not lead to increased engagement in the development of professional competencies within degree programs. It is possible (though untested in this study) that the more students work the less they believe the

University context to be authentic (perhaps due to a lack of the tacit requirements, expectations and consequences inherent in the workplace), leading to a strengthening belief that professional skills need to be learnt in industry. This would be a valuable avenue for further exploration. Drilling down to the 4 specific professional competencies that were surveyed (see Table 3), we can see that whilst there are some variations, the same pattern occurs across a range of different competencies.

3.4 Which competencies require a greater understanding of theory

Considering Q3 in Table 2, this question explored students' views regarding the extent to which different competencies required an understanding of associated theory. As expected, there was a significant trend to perceiving that technical competencies required a strong theoretical foundation than professional competencies. Possibly more surprising, however, is that increasing levels of professional experience tended to strengthen these views rather than weaken them, and this pattern is consistent across the individual competencies. For example, for respondents with <1 month of professional experience, the average rating (from 1 to 8) for teamwork was 6.34 (where 1=most needs theory and 8=least needs theory) whereas for respondents with greater experience, the average rating was 6.73.

4 SUMMARY AND ACKNOWLEDGMENTS

As noted in the introduction, understanding students' views regarding the development of professional competencies is important in terms of informing the ways in which engineering educators design engineering programs. The research reported in this paper suggests that it is flawed to assume that greater exposure to (or participation in) professional practice will lead to greater recognition by students of the value of professional competencies and hence engagement by students in our educational programs that focus in this area.

If we are to enhance our learning outcomes for students with respect to professional competencies, then it is likely that we will need a more nuanced understanding. Whilst this research has provided some useful insights into students' views on the development of professional competencies, it is clear that further investigation is needed to identify what drives the formation of these views. This is especially true with respect to what it is about professional practice that leads students to feel that their professional competencies should be developed in industry rather than University. Potentially this relates to perceptions of value and authenticity (especially in University contexts that lack the tacit requirements, expectations, and consequences inherent in the workplace), and it is this area that particularly warrants further investigation.

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RETHINKING THE NATURE OF EXPERIMENTAL LEARNING: MOVING BEYOND CONVENTIONAL LABORATORY EXPERIENCES

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ABSTRACT

Laboratory experimentation is an important educational tool across many disciplines, providing a mechanism for students to enhance their understanding of the relationships between theoretical models and physical reality. However, whilst laboratories are used extensively, the existing approaches to experimental learning have evolved little in the last 100 years, the intended learning outcomes are often poorly articulated and the connection between the learning outcomes and the student experiences is unclear. These limitations hasve meant that the development of laboratory experiences has tended to be driven by a combination of history, the capability of physical laboratory environments, and technological opportunity (e.g. the feasibility of rich simulations or remotely accessed laboratories) rather than pedagogic considerations or a deeper understanding of the role of experimentation within the educational process. Indeed many "new" laboratory innovations tend to only be technologically-enhanced versions of conventional experiences rather than leveraging the affordances of new technologies. In this paper we explore the nature of experimental learning and the extent to which we can achieve improved educational outcomes by a reconceptualization of the nature of this form of learning.

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1 INTRODUCTION

1.1 General Context

Laboratory experimentation has long been a distinctive characteristic of education within a range of disciplines, particularly those associated with the physical sciences (Hofstein & Lunetta 1982; Pickering 1993). The use of laboratory experimentation has become so embedded that the inclusion of laboratories experiences into the curricula is often mandated in many accreditation frameworks: e.g. from Engineers Australia accreditation criteria: "*3.2.4.5. Practical and 'Hands-On' Experience: There must be substantial hands-on practical experience manifested through specifically designed laboratory activities, investigatory assignments and project work….*" (Bradley 2008).

Despite their pervasiveness, there is however a lack of clarity regarding what defines experimental learning (not to be confused with experiential learning). Whilst predominantly focused on the active manipulation of a phenomena under study, most commonly it is discussed in terms of the physical laboratory experience of the student rather than by the underlying education purpose. This purpose is not inherently tied to activities within a physical laboratory setting, and yet we often treat it as though it were.

Over the last several decades we have seen technology used to construct laboratory activities that have begun to break the conventional model of a laboratory classroom. As two examples: remotely accessed laboratories (Ma and Nickerson 2006) enable students to access physical laboratories regardless of location and time; and simulations and virtual reality allow students to manipulate "experimental equipment" that might otherwise be too difficult (or too dangerous, or too expensive) to access. Despite the improved affordances offered by these new possibilities, the actual experimentation that is carried out has tended to adhere to the same underlying conceptual model. For example, most remotely accessible laboratories that have been developed tend to be remotely accessed versions of similar hands-on experiments, rather than an inherently new type of experimental activity.

In this paper we argue that this represents a missed opportunity. The emergence of new technologically-enabled laboratories should be providing a trigger for reconceptualising the nature of educational experimentation. We begin by considering the nature of existing experimentation, and then look at how these activities have begun to change. We then consider the core purpose of experimentation independently of the current physical implementations, and then what this might tell us about possible future models of experimental learning experiences.

1.2 Existing and Emerging Experimental Learning

Most current experimental experiences adhere to a relatively common model, based around laboratory activities. In a typical laboratory session, students will access, often only at designated times or for a relatively limited period, the laboratory apparatus. Within this time window they will conduct experiments (either individually or in groups) within a laboratory room using standardised equipment that provides a stylised or simplified version of a more complex real-world phenomenon. The experimental activity undertaken will exist somewhere on the spectrum between "cookbook" (i.e. with students following a set sequence of steps) and inquiry-based (i.e. with students given freedom to investigate a selected phenomenon).

To some extent this physical laboratory-based model of educational experimentation is a consequence of practical constraints: the need for physical access to (often expensive) equipment; the need to have a proximal relationship between a laboratory tutor and the students; the need to make the phenomenon under study evident and remove distractors; etc.

These constraints date back to the earliest examples of educational laboratories in the latter part of the 19th century[2] and since then the physical form of educational experimentation within a laboratory setting has remained largely unchanged (see, for example, Figure 1 illustrating an experimental laboratory from 100 years ago, which is quite similar to most contemporary teaching laboratories)!

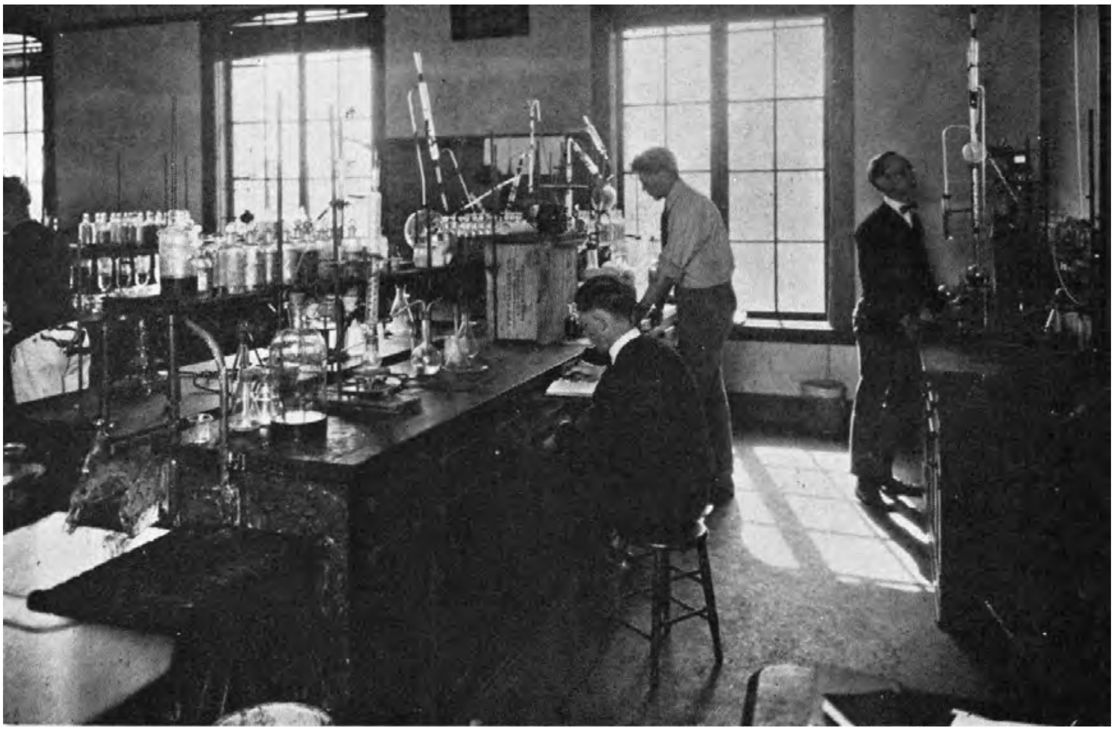


Fig. 1. The Caltech Chemical Laboratory c. 1923. (Image in the public domain: obtained from https://commons.wikimedia.org/wiki/File:Caltech_chemical_laboratory_1923.png)

[2] An excellent discussion of the development of the Cavendish Laboratory by James Clerk Maxwell in the 1870's is given at https://www.phy.cam.ac.uk/history/old_maxwell

The ubiquity (and longevity) of this physical laboratory-based model of experimental learning has often led to experimentation as being defined by this model, rather than by the underlying education purpose. For example, consider the following definition:

"Laboratory learning is <u>learning that takes place in a space where students can observe, practice, and experiment</u> with objects, materials, phenomena, and ideas either individually or in groups." (Seel 2012)

The result of having experimental learning commonly conceptualised as an activity

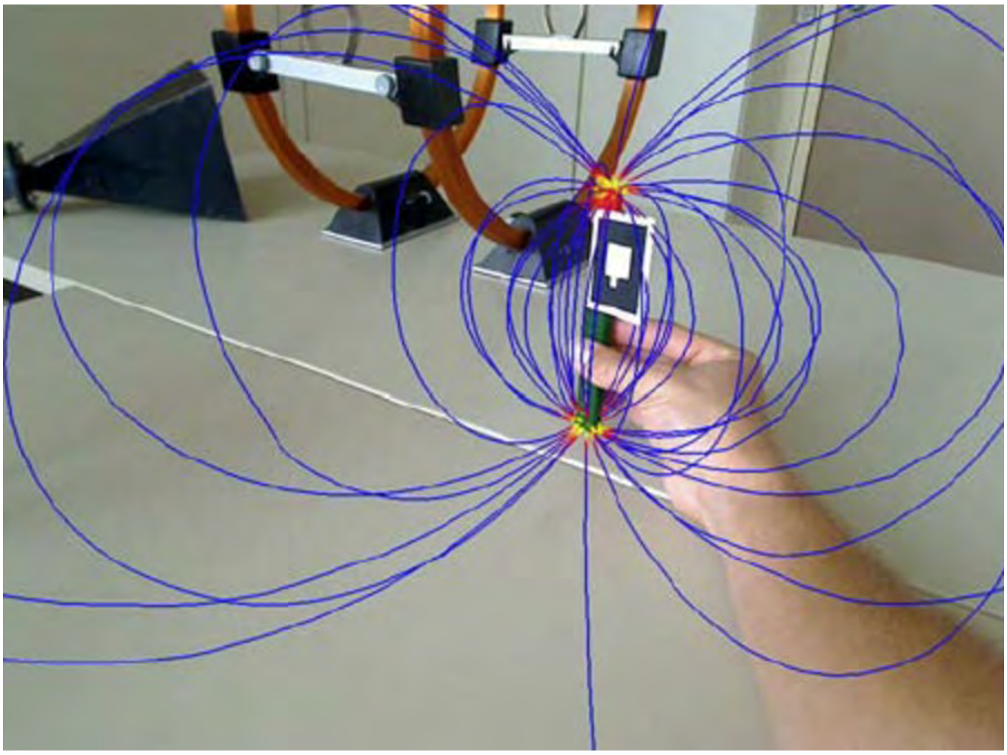


Fig. 2. The A magnetics experiment, where Augmented Reality is used to supplement the students view to show an "invisible" magnetic field. From (Buchau et al., 2009)

that occurs within a physical laboratory is that the nature of most experimental learning experiences has been relatively narrow, involving local manipulation of laboratory equipment and associated observation of the resultant behaviours.

Technology is however beginning to drive some changes to this model. Computational modelling tools have enabled simulations that allow students to manipulate the "experiment" in much richer ways than is often feasible with hands-on equipment. Networking technology has allowed physical labs to be instrumented and then controlled remotely (Corter et al., 2007), enabling enhanced access and the ability to share equipment between multiple institutions. Virtual reality has enabled a more immersive engagement with experiments. And most recently, Augmented Reality has begun to allow students to perceive elements of a laboratory phenomenon which were previously only indirectly sensed. As an example of this latter case, consider Figure 2 where AR allows a student to "see" a magnetic field.

These examples of the use of technology demonstrate experimental learning that is starting to diverge away from experiments based on “sit at a laboratory bench and manipulate the apparatus”. Nevertheless, the majority of extant examples are still based on adaptations of previous conventional laboratory activities and have used the technology primarily to enhance or supplement those activities rather than to create fundamentally new learning experiences.

This suggests the possibility of a missed opportunity. It is worth asking the question about whether there are new forms of experimental experiences that transcend the constraints implied by physical laboratory settings. Prior to considering this however it is worthwhile looking at what we know about the purpose of experimental learning.

2 CORE PURPOSE

The origins of laboratories within teaching programs dates back at least 150 years. Laboratories had existed well before then, but were originally established for the purposes of research. Their use in teaching was originally limited to providing demonstrations accompanying lectures rather than enabling student experimentation:

> *“In the catalogue for 1851-52 the statement is made that 'the chemical laboratory is amply furnished with apparatus and chemicals <u>for illustration of lectures in that department</u>*” (Whitman 1898) (emphasis in original).

Progressively though students became more actively involved in experimentation and by the beginning of the twentieth century it was well established. Debates did however continue over the relative benefits of the “Demonstration Method” versus the “Laboratory Method”, with the purpose of the latter being well described by Knox (1927) as:

> “*The laboratory method has been justified by advocates of this method on the ground that the manipulation of materials with proper directions develops a scientific attitude and a comprehension of acceptable methods of attack for the solution of new problems*”.

Interestingly, given the above comments on the physical model of a laboratory experience, Knox went on to say:

> “*[T]he term "laboratory method" will be employed in the popular sense, meaning a procedure wherein the pupils perform experiments individually or in groups*”

For the next 80-odd years there is little additional insight in the literature with regard to the purpose of experimental learning. There is much research into various experimental approaches and aspects such as student reactions to experimental methods, and evolving accreditation processes continued to refer to the need for laboratories (see, for example, the early Grinter report (Grinter 1955) and the much later ABET criteria (Accreditation Board for Engineering and Technology Inc 1999)). This work generally didn’t however flow through into considering the core purpose of the laboratory experimentation, or the intended learning outcomes of these activities.

This finally began to change at the beginning of the 21st Century. Work that emerged out of a 2002 ABET Colloquy on laboratory education resulted in the articulation of a taxonomy of thirteen learning objectives (Feisel & Rosa 2005) that might be relevant to laboratory activities. Whilst this taxonomy has subsequently been used in comparing different laboratory designs (see, for example, (Corter et al. 2011; Lindsay and Good 2005)) there has been little consideration more generally of its role in specific educational design of laboratory activities. Where such work has occurred, the focus has generally been on specific characteristics rather than broader design approaches. For example Terkowsky and Heartel (2014) explored the types of objectives and activities that might be suited to developing creativity.

An analysis of the ABET taxonomy highlights a useful (though not unexpected) pattern: almost all of the objectives are deeply grounded in a connection with a real-world physical reality. Consider, for example (Feisel & Rosa 2005):

> "Objective 1: … to make measurements of physical quantities."
>
> "Objective 2: … predictors of real-world behaviours … describes a physical event …".
>
> "Objective 6: … due to faulty equipment …"
>
> "Objective 7: … real-world problem solving …"
>
> "Objective 13: … human senses … real-world problems …".

The exceptions to this explicit connection to a physical reality are objectives 10 (communication), 11 (teamwork) and 12 (ethics). In this case there is potentially an implication that real-world environments might provide a useful context within which these objectives might be productively explored.

Given these observations, we can posit that the core underlying purpose of experimental learning is to engage students in understanding the nature of physical phenomena through engagement with (and often manipulation of) those phenomena, and particularly to understand the relationship between those physical phenomena and the conceptual models that we use to describe the phenomena.

Within this context the significance of using laboratory-based experimental equipment comes from their role as a proxy for a broader reality in which the phenomena might normally be experienced (Machet et al. 2012). Students use experimental apparatus to recreate simplified versions of naturally occurring phenomena (which may be physical, chemical or biological) in order to grasp the underlying principles and achieve learning objectives.

Recognising, however, that the core purpose of experimental learning is about engagement with physical phenomena and that the laboratory setting is simply one vehicle for achieving that engagement should allow us to then consider alternative ways in which experimental learning can be achieved, and to hence move beyond an assumption that experimental learning is synonymous with laboratory-based activities.

3 ILLUSTRATIVE EXAMPLES OF ALTERNATIVE EXPERIMENTAL LEARNING

We can illustrate a more inclusive (and diverse) view of experimental learning by considering several illustrative examples that go beyond controlled laboratory-based activities.

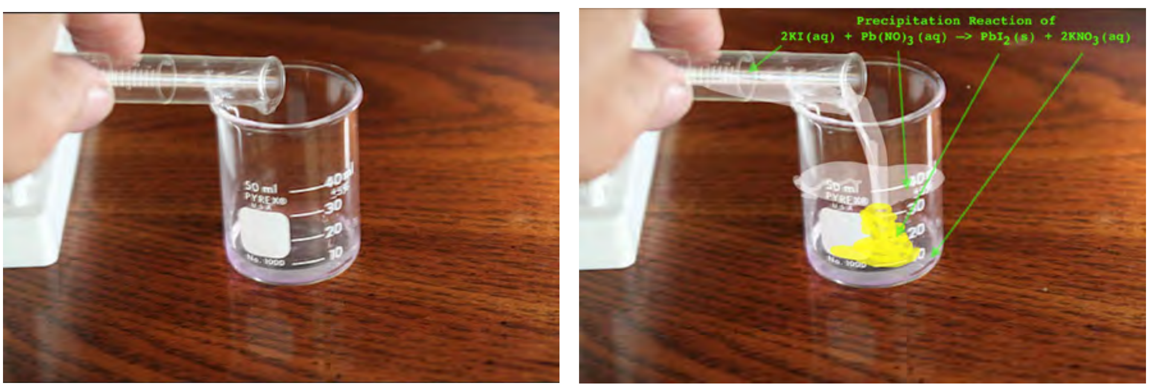
In this scenario, whilst elements of the experiment are virtual, the tight coupling between the “real” aspects and augmented aspects anchors the experience in the real-world and provides the student with the experience of manipulating reality whilst allowing a much richer set of experiences than might otherwise be the case.

Experimentation outside the lab: Figure 3 illustrates a hybrid experimental setup using augmented reality (discussed in more detail in (Lowe & Liu 2017)). In this scenario the real physical aspects of the experimentation that are readily accessible to students outside of a normal laboratory environment are supplemented by virtual versions of those elements which might normally not be available (due to reasons such as cost or safety). In some respects this has parallels with the concept of kitchen science (Jones 2011) but expanded to allow a much richer collection of experimentation than might otherwise be the case.

Experimentation embedded in the wild: The increasing available of cheap powerful and easy to use IoT devices provides the potential for directly monitoring real-world phenomena, rather than relying on the controlled environment of the laboratory. Consider, for example, a scenario where a student places wireless Bluetooth strain gauges onto a footbridge and then collects data from the sensors as they walk across the footbridge.

In this scenario the students are using the real-world as their laboratory and everyday activities as the phenomena being monitored.

Experimentation from citizen science. Citizen science, or alternatively crowd-sourced science, involves scientific research conducted (to varying extents) by the general public. Often this will result in large data sets which – apart from their broader use in



(a) (b)

Fig. 3. A student conducts a hybrid precipitation experiment, where physical equipment is overlaid with virtual materials. (a) without Augmented Reality; (b) with the augmented reality overlay (from (Lowe & Liu 2017))

supporting the original research objectives - could then be mined as part of exploring the phenomena under consideration.

For example, consider a student wishing to explore fluid flow who is able to access a subset of a large meteorology database to extract a small set of data relevant to localised air pressure differences and associated wind vectors. In this scenario they are obviously not manipulated the “real-world” but rather they are selecting a subset from the data that lets them explore relevant variations in the desired phenomena.

4 CONCLUSIONS

Whilst laboratory experimentation has long been seen as a crucial element of applied science and engineering programs, there has been only limited consideration given to the underlying purpose of these student experiences and how they address intended learning outcomes. The result has been a lack of creativity in designing alternative experiences – particularly those that enabled by emerging technologies, particularly those related to networking and augmented and virtual reality.

In this paper we have argued for a deeper consideration of the nature of experimental learning and provided some illustrative examples that begin to move us beyond the conventional (but typically unquestioned) model of manipulation of standardised equipment in a laboratory classroom.

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IS "IMPROVING THE QUALITY OF LIFE" THE ONLY SUSTAINABILITY ISSUE THAT IS RELATED TO ENGINEERING? – EXPLORING ENGINEERING STUDENTS' CONCEPTIONS OF SUSTAINABILITY

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ABSTRACT
UNESCO's (2021) report on engineering for sustainable development has emphasized the critical role of engineers in achieving the 17 Sustainable Development Goals (SDGs). Yet, there is a lack of clarity about the conceptualization or definition of sustainability (Moore et al., 2017), which makes it difficult to integrate sustainability into the curriculum. While Walshe (2008) conducted a study on high school students' conceptions of sustainability in the UK, there appears to be a lack of research conducted in the context of higher education. The study presented in this paper explores engineering students' understanding of sustainability in engineering and how it is influenced by their learning experience in the Integrated Engineering Programme (IEP) in University College London (UCL) . Taking a mixed-methods approach, a survey was administered to 139 first-year engineering students followed by individual interviews with 10 students. The survey contained a section which asked students to indicate the extent to which ten different sustainability issues (e.g. creating economic growth, saving lives) are associated with the field of engineering (Klotz et al., 2014). It was found that 65% of the students indicated that "improving the quality of life" is "very much" related to engineering, but less than 50% of them indicated that the remaining nine sustainability issues are "very much" related. Follow-up interviews suggest diverse understandings of sustainability among engineering students, with individual differences in their perception of the learning experience at the university. Findings from the study have important implications for the integration of sustainability in engineering education and will be discussed.

1 INTRODUCTION

As the world continue to face global challenges such as climate change and biodiversity emergency, there is a need for engineers to accelerate their efforts towards achieving UNESCO's Sustainable Development Goals (SDGs). Recognizing the critical role of engineers in sustainable development, accreditation bodies around the world have included outcomes that focus on ethical standards, responsibility towards people and the environment to the accreditation criteria of professional engineering programmes. For example, as indicated in the UK Engineering Council's (2020) accreditation criteria, engineering programmes are expected to develop students' ability "to evaluate the environmental and societal impact of solutions to broadly-defined problems".

Embedding sustainability in engineering education is not without its challenges. Although there has been a continuous effort to define and operationalize the concept of sustainability, it remains ambiguous due to its multidimensionality, making it difficult to integrate into the higher education curriculum (Moore et al. 2017). Previous studies have described a variety of approaches to implementing engineering education for sustainable development, ranging from courses about sustainability (e.g. Quist et al. 2006) to total curriculum redesign (e.g. Mesa et al. 2017). While many universities have sustainability as one of their core values, and have also stated what university graduates should know about sustainability, very little research has been published about what engineering students actually know about sustainability. To properly integrate the sustainable development goals into current education, it is necessary to understand students' conceptions of sustainability and current issues of sustainable development.

Thus, this study aims to explores engineering students' understanding of sustainability in engineering and how it is influenced by their learning experience in the Integrated Engineering Programme (IEP) at University College London (UCL).

2 CONTEXT

One of the key features of the IEP in UCL is the common curriculum structure shared by all engineering departments during the first two years of students' undergraduate studies, with shared objectives, format and assessment protocols across the different departments. The curriculum consists of the following key elements :

(1) Engineering Challenges: two five-week projects at the beginning of Year 1 introducing students to the role and scope of engineering;

(2) Scenarios: one-week intensive design projects for students to integrate critical engineering skills and knowledge developed through lectures;

(3) Design and Professional Skills: a structured discipline-focused programme to facilitate students' development of skills which they can apply and build upon in their Scenarios and Challenges (Hailes et al 2021).

While the aim was to develop a common syllabus that would cover a range of topics required by accreditation bodies (including but not limited to ethics, professional standards and sustainability), both the Scenarios and the Design and Professional Skills module are heavily tailored to each engineering department (Mitchell et al 2021), so students' experiences in these two modules can differ.

3 STUDENTS' CONCEPTION OF SUSTAINABILITY

Previous research investigating engineering undergraduates' conception of sustainability seems to be scarce. In early 2000s, Walshe (2008) investigated high school students' conceptions of sustainability in the UK and found wide variety of understanding of sustainability among the students which included the nature, purpose and timescale of sustainability. Similarly, Carew and Mitchell (2002) found substantial variations in the way chemical engineering undergraduates understood sustainability: from vague and incomplete understanding to comprehensive and elaborate understanding of sustainability. Also, while there is growing consensus among researchers that conceptions of sustainability must include consideration of environmental, economic, and social factors (Purvis et al 2019 ; Hansmann et al 2012), Zeegers and Clark (2013) found that many of the students majoring in environmental management and sustainability in a university in Australia leaned towards an environmentally focused perspective of sustainability.

4 METHODOLOGY

4.1 Participants

Table 1 below presents the demographic information of the survey participants. A total of 139 first-year engineering undergraduate students from a UK university participated in the study. Majority of them are between 17 to 21 years old, except for 3 mature students who are 21 years or older. As presented in Table 2, a total of 10 students who completed the questionnaire volunteered to participate in an individual follow-up interview.

Table 1. Demographic information of the survey participants

	Frequency	Percentage
Gender		
Female	41	29.5
Male	74	53.2
Unreported	24	17.3
Engineering Department		
Biochemical Engineering	3	2.2
Chemical Engineering	13	9.4

Civil, Environmental and Geomatic Engineering	11	7.9
Computer Science	35	25.2
Electronic and Electrical Engineering	22	15.8
Mechanical Engineering	26	18.7
Medical Physics and Biomedical Engineering	9	6.5
Unreported	20	14.4

Table 2. Demographic information of the interview participants

Student	Gender	Engineering Discipline
1	Female	Biomedical
2	Male	Electronic and Electrical
3	Male	Chemical
4	Female	Chemical
5	Female	Biochemical
6	Male	Biochemical
7	Male	Chemical
8	Male	Chemical
9	Female	Chemical
10	Male	Electronic and Electrical

4.2 Instrument

The survey instrument consisted of three key sections with a total of 49 questionnaire items. The first section (34 items) asked students to self-assess 34 generic skills items in terms of the extent to which they agree that each skill is important to becoming a successful engineering on a 5-point Likert scale ranging from 1 (very unimportant) to 5 (very important). The second section (10 items) contained an item adapted from the Sustainability and Gender in Engineering (SaGE) questionnaire which asked students to rate the extent to which ten different sustainability issues (e.g. creating economic growth, saving lives) are associated with the field of engineering (Klotz et al. 2014). This section employed a 5-point Likert scale ranging from 0 (not at all) to 5 (very much so). The last section required students to provide their personal information, including their gender, age, domicile (UK, EU or Non-EU), ethnicity and the engineering department which they are from (five items).

4.3 Procedures

An explanatory sequential mixed-methods design (Creswell 2014) was adopted in this study, such that the follow-up interviews will allow further investigation of students' conception of sustainability in the context of engineering.

Ethical approval for the research was obtained prior to data collection.

A purposive sampling approach (Johnson and Christensen 2014) was undertaken, such that an email invitation to participate in the survey was sent to all first year engineering students in the university where the study was conducted, at the beginning of the first term, in October 2022. The questionnaire required approximately 30 minutes to complete.

Individual interviews were conducted with 10 students, after the first term between January to March in 2023. The interviews were guided with questions designed to elicit ideas related to students' experiences of learning about sustainability in the university. Findings from the questionnaire were also used to stimulate discussion with the interviewees to maximize the alignment between the questionnaire and interview data (Harris and Brown 2010). All the interviews were conducted online via Microsoft Teams and lasted for about an hour.

5 RESULTS

5.1 Findings from the survey

In general, more than 50% of the survey participants indicated that all 10 sustainability issues are much (i.e. rather much or very much so) related to engineering (Table 3). It was found that majority of the students indicated that "improving the quality of life" (65%) is "very much" related to engineering. However, less than 45% of them indicated that the remaining nine sustainability issues are "very much" related.

Nonetheless, the survey findings suggest that students have quite a balanced view of sustainability which includes economic, social and environmental sustainability. At the same time, it is interesting to note that around 30% of the students believe that creating economic growth (33.1%), preserving national security (33.1%), including women as professional colleagues (31.7%) and feeling a moral obligation to other people (36.7%) are only related to engineering to some extent. In other words, there are a group of students who are less able to relate the economic dimension and some of the social dimensions of sustainability to engineering.

Table 3. Students' perception of issues related to sustainability

In your opinion, to what extent are the following associated with the field of engineering?	Frequency (Percentage)				
	Not at all	Only a little	To some extent	Rather much	Very much so
Creating economic growth	1(0.7%)	9 (6.5%)	46 (33.1%)	50 (36%)	33 (23.7%)

Preserving national security	2 (1.4%)	8 (5.8%)	46 (33.1%)	42 (30.2%)	41 (29.5%)
Improving quality of life	1 (0.7%)	1 (0.7%)	12 (8.6%)	34 (24.5%)	91 (65.5%)
Saving lives	1 (0.7%)	3 (2.2%)	33 (23.7%)	42 (30.2%)	60 (43.2%)
Caring for communities	2 (1.4%)	8 (5.8%)	33 (23.7%)	47 (33.8%)	49 (35.3%)
Protecting the environment and biodiversity	1 (0.7%)	7 (5%)	30 (21.6%)	48 (34.5%)	53 (38.1%)
Including women as professional colleagues or stakeholder / participants in the field	6 (4.3%)	15 (10.8%)	44 (31.7%)	39 (28.1%)	35 (25.2%)
Including racial and ethnic minorities as professional colleagues or stakeholder / participants in the field	3 (2.2%)	15 (10.8%)	38 (27.3%)	50 (36%)	33 (23.7%)
Addressing societal concerns	2 (1.4%)	8 (5.8%)	25 (18%)	55 (39.6%)	49 (35.3%)
Feeling a moral obligation to other people	2 (1.4%)	11 (7.9%)	51 (36.7%)	44 (31.7%)	31 (22.3%)

5.2 Findings from the interview

While findings from the survey suggest that engineering students do have quite a balanced view of sustainability, engineering students who participated in the interview tended to lean towards an environmental perspective. When asked what is their understanding of sustainability, all of the student interviewees, regardless of engineering discipline, talked about the environmental aspect of sustainability. For example:

> *My understanding is if something is sustainable then it will not degrade the environment and the well-being of future generations. I do tree planting at home, so I guess that's something that is focused on sustainability.* (S2, Electronic and Electrical)

Majority of them also referred to the concept of time as they spoke about things lasting into the future, suggesting that students do a have 'future perspective' of sustainability.

> *I think for me, sustainability means long lasting. So it's like materials or things that can constantly be refreshed and it's not damaging to the environment because we're not exactly taking away from it at the end of the day, it's still being put back in the same way so that everything stays.* (S6, Biochemical)

However, few considered the possibility of changing or improving the future as part of sustainability, except for one student who identified and envisioned alternative futures which are more just and sustainable:

Using only the resources that you need. But that's one part of it, another way of engaging in it is trying to be fair between people, like offer everyone proper working conditions etc. So, to make sure that everything is sustainable, try to go for the better alternative that benefits everyone. (S1, Biomedical)

S1 was also the only student who was able to identify the issue of intra-generational equity, which is related to social or economic sustainability.

An interesting finding from the interview was that students from the different engineering departments have different experiences of learning about sustainability. As illustrated by the excerpts below, a biomedical engineering student and a chemical engineering student described their experience of learning about sustainabiltiy as "optional", such that it depends on whether they choose to focus on sustainability for their assignment.

But we haven't done like any sustainability related issues, except for Engineering Challenges in which we only did a bit of it. For the assignment, we didn't have to consider any environmental factors, unless you chose to do risk analysis. (S1, Biomedical)

In Design and Professional Skills, there's a technical communication component, and I did a research project about biofuels. It was just by chance that my topic was about something related to sustainability. A lot of people chose topics which are completely different from mine. (S3, Chemical)

On the other hand, a biochemical engineering student and an electrical and electronic engineering student described their experience of learning about sustainability as being an integral part of their course.

During Design and Professional Skills, I think they've kind of specifically gone over reasons why engineering practices should be sustainable and how it affects the quality of life. And I think it's really reiterated throughout all our courses and I think in one of my biology focused lessons. We were looking at different reports and they were really emphasizing on how those research or experiments were done in a sustainable way to minimize bad effects that may come from the research and how it would be more beneficial for everyone if they were carried out in a more sustainable way. (S6. Biochemical)

I think it's in Design and Professional Skills that we have to go through the life cycle of a electrical component, think about how does it affect the environment, and to see like how sustainable it is and how to improve it over time? (S10, Electronic and Electrical)

6 SUMMARY

This paper explored engineering students' understanding of sustainability in engineering and how it is influenced by their learning experience in the Integrated Engineering Programme (IEP) in UCL.

In contrast to the findings from the study by Zeegers and Clark (2013), first-year engineering students in thisstudy have quite a balanced view of sustainability. The finding that the student interviewees tended to have an environmental perspective of sustainability in engineering suggests a possibly strong influence of the curriculum given that the interviews were conducted towards the end of the term, while the survey was conducted at the beginning. This is supported by the comparison of student experience in the different engineering departments, which suggests that students' conception of sustainability is influenced by the course content and assessment. In other words, our findings suggest that one module (i.e Design and Professional Skills) alone is insufficient to broaden students' understanding of sustainability. In fact, it seems to have focused students' attention to specific aspect of sustainability which students find easier to relate to their discipline. To address these issues, steps can be taken to integrate sustainability more comprehensively into the engineering curriculum, including incorporating sustainability into all engineering courses, not just a single module. This can be achieved through proposing the development of learning outcomes that explicitly address sustainability and the use of teaching methods that encourage critical thinking about sustainability. Additionally, faculty development programs can be implemented to support instructors in integrating sustainability into their courses. Finally, follow-up studies with students in different stages of their degree programme is needed to determine whether there is any evidence of critical thinking about sustainability, whether their conception of sustainability changes and what aspects of the IEP influence any of these changes.

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European and National Strategies Supporting Development and Implementation of Continuing Engineering Education at Scandinavian Universities

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Keywords: *Continuing engineering education, lifelong learning, engineering education, strategy, future*

ABSTRACT

Lifelong learning (LLL) and continuing engineering education (CEE) have been on the European Union's agenda for almost three decades, formally initiated by the *European Year of Lifelong Learning* in 1996 and reinforced with several initiatives targeted at LLL since then. The current initiative, the European Year of Skills 2023, aims to promote a mindset of reskilling and upskilling. Nonetheless, before 1996, some universities were already developing diverse CEE activities and collaborating with external stakeholders such as the local industry. Many of these activities, however, have been initiated by passionate university staff or based on personal relationships within the organization. CEE activities have therefore, for most universities, been an unregulated and sideline area, and at some institutions, it is organized in private units associated with the university. This is despite the fact that the individual Scandinavian countries have national education policies regarding continuing education (CE), and each university has more or less explicit visions and strategies for CE activities.

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This research aims to answer the question of how European initiatives and Scandinavian national strategies support the implementation and development of CEE. Additionally, it will attempt to predict the future of CEE in Scandinavian countries by examining the beliefs of actors in CEE. The study will document the current state of initiatives and strategies and will be based on twenty interviews from ten Scandinavian universities.

1 INTRODUCTION

The grand challenges of the 21st century underscore the need for knowledge and competence development in Western societies, especially in the field of engineering. The increasing threat stemming from the environmental crisis has led to a push from both political leaders and broader society for engineers to help ensure a turn to sustainable production. These demands are reflected in the United Nations SDGs, which include goals regarding the implementation of green energy and climate actions [1] (United Nations, 2015).
At the same time, the evolving role of technology, as marked by the development of Industry 4.0, has changed engineering practices. Especially, the need for professional engineers to possess an ever-changing range of digital and technological skills has received political attention. This is reflected in the goals of the *European Year of Skills 2023*, where one of the main goals is the up- and reskilling of workers to implement green and digital transformations to secure sustainable economic growth in Europe.
At the same time, individuals are spending a greater part of their lifespan in the workforce, which is why formal learning activities are no longer bound to students participating in traditional formal education. The traditional cycle of education, employment, and retirement may be replaced with active employment supplemented with periods of participation in formal and informal CE, thereby securing LLL. This trend is emphasized by the objectives put forward by the commission behind the European Skills Agenda, where one of the goals states that in 2024, 50% of adults aged 25-64 should participate in learning over a period of 12 months. In 2016, that level was 38% [2] (European Commission, 2020).
Not surprisingly, Higher Educations Intuitions (HEIs), e.g., universities, are expected to play an important role in the ongoing transformations. The participation of universities as an actor in the field of LLL is not a new one. Yet, the development and facilitation of CEE varies greatly between European universities. From formal accredited courses, such as masters, to short informal activities such as MOOCs, from being partly state financed to being financed by employers or participants, the political and institutional framework has a vital influence on the development of LLL through CEE.
The focus of this paper is to examine the political strategies for the development of CEE at both an international (European) and national level, with a specific emphasis on the Scandinavian countries. This will be set against visions of the future of CEE put forward by academic staff at ten Scandinavian universities. This leads to our research question:

How are European initiatives and Scandinavian national strategies supporting the implementation and development of CEE, and what will be the future?

This paper will consist of a description of the methodology behind the data collection, which consists of interviews and document analysis. This will lead to the analysis, which builds upon a description of initiatives implemented at a European, national, and institutional level. Lastly, the different initiatives and imaginaries will be compared and utilized as a basis for a discussion of the future directions of CEE at European HEIs.

2 METHODOLOGY

This study employs a qualitative research approach to explore and comprehend the development and implementation of CEE at Scandinavian universities. The study employs document analysis and interviews to gather data, including reports, white papers, articles, and other relevant documents related to EU aims, national strategies and legislation, and university practices on CEE. Ten universities were included in the study, and two participants from academic staff were interviewed in each university, selected based on their experience and practice in the field of CEE. The participants were informed about the study's purpose, and their consent was obtained before data collection. To ensure consistency and coverage of the research question, a semi-structured interview guide [3] (Kvale 2004) was used to structure the data collection. How actors in CEE perceive, understand, and implement activities within their respective institutions, a loosely structured interview guide was used, with the following headline questions:

1. Background Check: Are you aware of national strategies for LLL? Does your university have an explicit strategy for CEE initiatives?
2. Future Needs: In your opinion, what are the future needs or challenges that require new approaches in the context of CEE? How do you anticipate disruptive changes influencing the field of CEE?
3. Awareness of Initiatives: Are you aware of any ongoing initiatives or experiments within your institution that are exploring new approaches to CEE?
4. Crystal Ball: What do you envision for the future of CE, particularly in terms of new paradigms for knowledge flow between industry, universities, and professional engineers?

Due to the Corona pandemic, all interviews were conducted online, and audio recording was done with the participants' consent. NVivo software was used for data analysis, which involved coding the interviews and identifying themes. An inductive approach was used, developing themes and categories from the interviews, rather than using theories or a framework. Ethical considerations were taken into account throughout the research process. Participants were informed of the study's purpose, and their consent was obtained before data collection. Participants were also informed that they could withdraw from the study at any time without hesitation. Participants' anonymity and confidentiality were ensured, and data was stored securely. The study was conducted in compliance with relevant ethical guidelines and regulations of Aalborg University.

3 FINDINGS

Since the *European Year of Lifelong Learning* in 1996, various political motivations and organizational strategies have led to the initiation of diverse forms of CE aimed at facilitating LLL for professional engineers. The purpose of this chapter is to document the different transnational, national, and institutional initiatives, aims, etc., shaping the development and implementation of CEE in Scandinavia.

The importance of LLL has received renewed political attention, as the EU marked 2023 as the *European Year of Skills*. Specifically, there has been a renewed focus on the upskilling and reskilling European workers, especially in the fields of environmental and digital technologies, with the hope of securing sustainable development, innovation, as well as economic competitiveness for European companies. Another goal put forward on the agenda is to counteract the problem of a lack of skilled workers available for small and medium-sized European companies. More than three-quarters of all companies in the EU report problems finding employees with the necessary skills. In addition, already in 2021, more than 28 occupations, including engineering and IT, announced shortages in skilled workers. [4] (European Commission 2022). All of this points to the need for further development in the field of CEE.

A range of both financial and political initiatives have been implemented to support this development at a European level. Firstly, there has been a growing focus on the importance of collaboration between EU commissions, member states, HEIs, and companies to ensure the relevance of initiatives in place to secure the up- and reskilling of workers. The need for collaboration between different political and educational institutions was emphasized by T. Breton, Commissioner for the European internal market: "*Europe's strength resides in its talent, including engineers, researchers and entrepreneurs. To achieve our Digital Decade and Green Deal goals, we want to support our companies, in particular SMEs, in hiring, training and keeping talent*."

One way to promote LLL in Europe is to continue ongoing initiatives such as the *European Skills Agenda* and the *European Strategy for Universities*, which propose actions to secure skill development and facilitate LLL. Additionally, a large sum of EU funds is being utilized to support the implementation of LLL and training initiatives, such as through the Erasmus+ fund.

At the national level, the need for LLL, including Continuing Education and Training (CET), is widely recognized by political institutions in Scandinavia. Similar to the basis for the European agenda, there is a strong focus on the need for collaboration between HEIs and the labor market to meet the need for skilled workers, particularly in the fields of STEM and ICT. In 2019, the *Nordic Network for Adult Learning*, a collaboration between Nordic countries supported by national ministries, put forward sustainability, equality, and digital skills at the core of their 2030 goals for further education (European Commission 2020).

Although there is collaboration between Scandinavian countries in the field of CE, there are different legal frameworks in place across the countries to help individuals develop their competences through their professional careers. For example, in Denmark, HEIs are legally required to plan CE activities in a way that allows participants to work alongside their studies. In Norway, employees after three years of employment have the right to receive up to two years of educational leave. Overall, there is a strategic focus in Scandinavia on ensuring as many people as possible have access to upskilling and reskilling activities that fit the needs of the labor market, although the strategy behind how this is facilitated differs. One recurring strategic focal point in Scandinavian policies is the need for flexible LLL opportunities, primarily facilitated through digital platforms, making them accessible across time and space. Another use of digital tools to make learning accessible, brought forward in both EU and Scandinavian universities, is using digital micro-credentials, through which individuals can receive the needed knowledge over a short time span.

Another political strategy implemented to ensure the accessibility of CET is through the recognition of prior learning. In Sweden, Norway, and Iceland, individuals' prior

learning gained through formal education or work experience is taken into consideration when granting admission to LLL activities, making upskilling through CET accessible to individuals with a non-traditional or vocational background.
Lastly, the availability of accessible and relevant guidance to professional adults who wish to further their education is emphasized as a necessary strategy to secure relevant competence development in Scandinavian societies. Traditionally, guidance related to CET has been delivered by the individual universities, making them partial to their own offerings. In the future, individuals should have access to an overview of existing LLL activities, as well as guidance that takes their personal and professional goals into consideration.
A constant factor in Scandinavian countries is the significant influence of political institutions, primarily the educational ministry, on the development and facilitation of CE, including CEE. Due to the strategic goal of making further education accessible to the broader population, many CEE activities are partially funded by the government, which limits the financial burden on individuals or companies participating in such activities. To be eligible for government funding, educational activities must be ECTS accredited, which is why many CEE activities at Scandinavian universities fall under the category of "open-university" courses, such as formal, scheduled courses like Masters, MBAs, or single-subject courses. In practice, this means that many CEE activities span over longer periods and have limited flexibility. However, many Scandinavian institutions, such as universities or private companies, also offer commercially based CEE activities. These activities do not receive government funding, which is why the legal framework for these activities is more flexible than that of accredited courses, making them more open for collaboration with external stakeholders. The commercial CEE initiatives make up a broad spectrum of programs, such as commercial Masters, shorter courses, or MOOCs.
The strategy for LLL at HEIs is apparent in how Scandinavian universities facilitate CEE, but there is not a singular approach. Some universities primarily offer LLL through internal units or decentralized structures, with individual departments handling CEE activities. Other institutions have set up external units, such as holding companies. Similarly, in some institutions, the majority of activities consist of Open University courses, often with individual enrollment and a close link to BS.C and MS.C curricula, while in others, commercial programs created in collaboration with companies constitute the bulk of activities.
According to *The Nordic STEM report* (2021), which is based on interviews with 20 members of academic staff from Danish, Finnish, Icelandic, Norwegian, and Swedish universities, there are many diverse organizational strategies and visions for the future of CEE [6] (Nordic Engineering Hun (NordEnHub) 2021). Generally, the interviews reflect the belief that in the future, CEE will play an important role across HEIs and the labor market: " [*…], if we're going to work until we're 70 we have to have a system that can handle 45, 50-year-old engineers coming back and taking a one-year master's degree to re-skill, because what they studied 25 years ago isn't valid anymore.*"
Therefor many universities points to a need for a stronger collaboration between university staff and companies, when facilitating CEE: "*I think in a field of engineering is [important] that that we sit down with the company […] to recognize the learning, what they need*". Likewise, some interviewees underscore the need for flexibility when facilitating learning aimed at professional needs "*One of the aims of this Department is to be in very good coordination with the industry and we want to be. I don't know how we expect to be quick to adapt because there's a lot of speed in the industry now*".

Some of the restraints that prevent flexibility in the future development of CEE derive from the legal framework connected to the Open University courses: "*If we take out one module from an ordinary course, we are not allowed to deliver that for payment. They have to change that, so it gets easier for us to deliver what the market needs.*" In this way, the political actions aimed at making CEE more accessible also limit the potential developments in the field. Additionally, internal planning and the lack of incentive structures are put forward as reasons that may hinder the implementation of CEE: "*It is really, really difficult, because our model is that people [academic staff] have a full schedule, and then, we must try and push more teaching into it."* This statement recurs in most interviews with staff from Scandinavian universities: "*So, you know what is it payback of this? So, I said that there has to be very clarified, so I don't see that happening. And I don't see that happening over the next five years either to be honest*".
Likewise Scandinavian universities point to the need for flexibility to ensure that the outreach activities meet the needs of professionals. This is reflected in the pedagogical- and didactical framework "*[…] would probably need to develop the university pedagogic courses that our teachers take to look into the peculiarities of conditions and education of professionals, people working full time. Because it has to be slightly different, it has to be time efficient for the participants, not for KTH."* One way to create more flexibility is through the utilization of digital teaching. Generally, there is a wide belief that online learning activities would play a larger role in the future: "*More and more people would like to attend workshops online*". For some universities this is connected to new course types: *"[…] in the coming years, we will have to establish lot of smaller courses, you know, that gives, what is it called, microcredits"*.
There are clear differences in the imaginations of the future of CEE across Scandinavian universities, especially in the perceived required learning outcomes from the outreach activities. While some organizations prioritize the need for skill sets in technological fields such as engineering or IT, which are also prioritized in the European and national strategies, other universities give precedence to a completely different set of competencies.: "*[…] Yeah, so mostly of our own organize our own engineers come to university look for more project management, for more leadership education. They are not actually looking for education in the field of technology or in their own field,*". This understanding highlights the importance of collaborating with companies and interest groups while developing CEE courses, to ensure that the activities developed meet professional demand.
The common thread in all the above statements is the belief that CEE will have a larger role to play in the future. However, to facilitate this development, Scandinavian universities need to rethink their role in the broader society: "*[…] the borders between university courses, some programs and the industry and the continuous education programs and courses, that will have to become much more fuzzy, and dissolved. We have to be dealt with as one thing, not as three different things."* But if the organizations succeed in this change, it will result in great possibilities for institutional development: *"[…] we have been involving a person from KTH, the University in Stockholm where we had some persons that also dig a little bit deeper into the future of continuous learning so we have a report from him and he says, that maybe in the future we have as much students as like ordinary students as we have continuous learning students and from the working industry.*"

4 SUMMARY AND FUTURE DIRECTIONS

Overall, there is a great belief that LLL through CEE will play an important societal role across European and Scandinavian political institutions as well as in Scandinavian universities. This is reflected in the transnational and national strategic support and initiatives, such as the financial support to the institutions facilitating CEE and the highlighting of the importance of collaboration between HEIs, political actors, and companies. As emphasized by the goals of The *European year of Lifelong Learning* and the *Nordic Network for Adult Learning*, there is a specific focus on skills needed in the fields of IT and technology to help companies transition to sustainable production.

The political support for LLL is not new in the Scandinavian political sphere. To further the accessibility of CEE, financial initiatives are set in place to minimize the monetary burden of the participants. Likewise, policies regarding flexible structures and recognition of prior learning aim to make it possible for individuals to participate in both formal learning activities and active employment. Future strategies for furthering participation in CE include supporting flexible learning through digital learning platforms and individual guidance.

Generally, the actors facilitating CEE at Scandinavian universities possess the same beliefs as those found in the transnational and national political spheres. There exists a belief that in the future, CEE activities will make up a large part of the universities' outreach activities, facilitated in close collaboration with external partners, such as companies. Yet for this development to take place, the institutions underscore the need for flexible structures when developing new outreach activities, including delivery, teaching, and incentive structures, to meet market demands. Also, there is a need for better communication with companies and the broader society to ensure the relevance of the learning facilitated through LLL activities. But if universities succeed in this transformation, the outcome will lead to institutions available to facilitate learning throughout engineers' work life.

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EXPLORING THE LINK BETWEEN SPATIAL AND COMMUNICATION SKILLS IN ENGINEERING STUDENTS

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ABSTRACT

Industry leaders rarely remark that the technical skills of engineering students are lacking; however, they frequently indicate that new engineers should be better prepared in communication skills, particularly written communication skills. In contrast, the visualization ability, or spatial skills, of engineering majors are typically excellent. Prior research has demonstrated that spatial ability is a significant predictor for graduating from STEM fields, particularly in engineering. This paper is part of a larger project that is exploring whether these two phenomena – poor written communication skills and well-developed spatial skills – are linked. In other words, is there a negative correlation between these two types of skills for engineering students? Data for this study was collected from first-year engineering students at a large university in the U.S. An online survey was administered that consisted of two validated spatial visualization tests, a verbal analogy task, and questions regarding

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students’ self-perceived communication ability. Student scores on spatial visualization tests and a verbal analogy task were compared between student groups and students’ perceived ability to communicate. Results identified statistically significant differences in test scores between domestic and international male students on all three tests. Interestingly, no gender-based differences were observed in spatial skills. Results from this study will contribute to future exploration of the link between spatial and technical communication skills. Results can also help inform the development of an intervention aimed at improving the written technical communication skills of our engineering students by helping them learn to write about spatial phenomena.

1 INTRODUCTION

1.1 Spatial Skills in Engineering

In the 1950s it was established that spatial skills are correlated with success in engineering and STEM (Super and Bachrach 1957, 24). Recent research has validated the claim that spatial skills are a reliable predictor of success in engineering disciplines and engineering careers (Uttal and Cohen 2012, 157) and is a critical skill in developing expertise in STEM (Wai, Lubinski, and Benbow 2009, 827). Research has shown marked differences in spatial skill ability, particularly in mental rotations, based on gender and socioeconomic status (Lauer, Yhang, and Lourenco 2019, 544), which could help explain the lack of representation of female and underrepresented minority students in engineering. However, there is a large body of evidence that spatial skills are malleable and can be trained, which can improve students' likelihood of success in engineering through interventions and training (Sorby 2009, 477).

1.2 Technical Communication Skills in Engineering

Another important skill for engineers to have is technical communication (Felder and Brent 2003, 13). Research has shown that technical communication abilities are crucial for engineers’ success (Alley 2013; Nathans-Kelly and Nicometo 2014; Winsor 2013), but engineers often overestimate their technical communication abilities (Donnell et al. 2011, 3). Interventions for improving engineers’ communication skills span a multitude of approaches, including courses and assignments that utilize interdisciplinary contexts for writing, which have resulted in improved grades and decreased writing times (Bertheoux 1996, 108; Boyd and Hassett 2000, 412). Other courses have taught engineering students writing skills that utilized self-reflection, which improved experimental lab report writing (Selwyn and Renaud-Assemat 2020). However, longitudinal studies that would demonstrate the durability of these interventions have not been conducted. Furthermore, due to the time and resource costs incurred to develop and sustain these courses, alternative approaches that could improve technical communication skills are desired.

1.3 Spatial Skills and Technical Communication

This study begins an exploration of a potential link between spatial thinking and technical communication skills. The overarching hypothesis is that spatial and technical communication skills are negatively correlated for most engineering students. If a negative relationship is found, an intervention could be developed in a future project to help these students learn to write about spatial phenomena. This paper is the first step in investigating that relationship.

2 METHODOLOGY

2.1 Participants

Participants were first-year undergraduate engineering majors at a large research university in the United States (U.S.). The students were enrolled in the second course of a two-course sequence taken by all engineering majors at the university. They had explicitly practiced spatial thinking skills in the first-semester course, through two weeks of in-class activities and graded assessments. Most students in the U.S. do not experience intentional spatial thinking content in formal education until those two weeks in that first-year course. Their training and practice with written communication came from their experiences prior to college as well as any communication courses they may have enrolled in in their first semester at the university.

Of the approximately 1200 students enrolled in the second-semester course, 115 participants were recruited for the study. Participating students received a small incentive for their participation in the form of a Visa gift card. Five participants were not included in the analysis because they did not complete the entire set of instruments, yielding a sample size of 110 for the analysis. This study was conducted with oversight from the Institutional Review Board for the university. Results from the demographic survey showed that 76 participants self-identified as male (M), 33 as female (F), and 1 chose not to disclose their gender identity. Of the 110 participants, 60% (39M, 27F) self-identified as a domestic student (meaning from the U.S.), 37% (35M, 6F) self-identified as international students; 3 (3%) students did not respond to this question.

2.2 Instruments

A number of separable spatial factors have been identified by psychologists over the years and tests have been developed to determine spatial skill levels for many of these factors. For this study, two measures of spatial skills were employed: the Mental Cutting Test (MCT) (CEEB. 1939) and the Mental Rotation Test (MRT) (Vandenburg and Kuse 1978, 599). With the MCT, students are shown an object with an imaginary cutting plane slicing through it and are asked to determine what the cross-section looks like from the choices given. There are 25 points possible on the test and it must be completed within 20 minutes. Anexample problem from the MCT is shown in Figure 1.

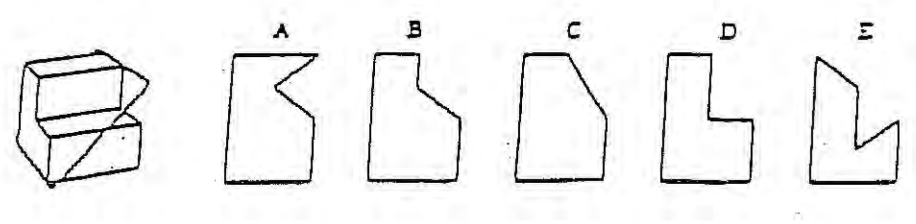

Fig. 1. Sample Problem from the MCT (Correct Answer = D)

In addition to the MCT, participants completed the MRT. An example problem from the MRT is shown in Figure 2. Although not as difficult as the MCT, the MRT has strict time limits and can be challenging for many students. Further, the MRT was included in this study because mental rotation skills have been shown to be important to overall success in engineering (Sorby 2009, 476) and speeded mental rotation tasks exhibit some of the largest gender differences in spatial ability (Voyer

2011, 267). This test is completed in two sessions of 3 minutes each with 12 items in each session. With the MRT, participants are presented with a criterion figure on the left and are instructed to find the *two* figures on the right that are rotated views of the criterion object. Scoring for this is 1 point if they identified both rotated views of the object, and 0 points if they fail to identify both.

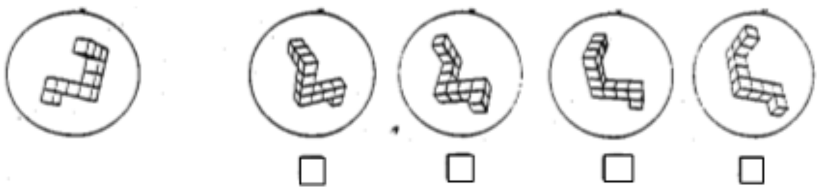

Fig. 2. Sample Problem from MRT (Correct answer is 1 & 3)

In addition to the spatial instruments, we administered a test of verbal skill level. The test was a verbal analogy task that consisted of 16 items. There was no time limit for the verbal analogy task. An example problem from the verbal analogy task is shown in Figure 3.

WOOD : (______) :: BUTTER : KNIFE

a) String b) Paper c) Saw d) Drill

Fig. 3. Sample Problem from the Verbal Analogy Task

In addition, participants responded to the following prompts on a 5-point Likert scale (1=Strongly Disagree, 2=Somewhat Disagree, 3=Neither Disagree nor Agree, 4=Somewhat Agree, 5=Strongly Agree).

- Q1: “I am confident that I am able to follow the instructions to efficiently put together a dresser from Ikea”. (Image shown)
- Q2: “I am confident that I am able to come up with appropriate words or phrases when I am in a conversation with someone talking about my non-technical ideas”.
- Q3: “I am confident in my ability to communicate my engineering ideas using verbal descriptions (words) that non-engineers can easily understand”.
- Q4: “I am confident that I am able to express my thoughts, in writing, so that other engineers can easily understand my ideas”.

2.3 Data Analysis

All analyses were conducted in RStudio 023.03.0 Build 386. Twelve t-tests were conducted. Specifically, for each of the three instruments measuring skills (MCT, MRT, verbal analogy test), t-tests were run to compare means between these groups:

- Male Domestic vs. Female Domestic
- Male International vs. Female International
- Male Domestic vs. Male International
- Female Domestic vs. Female International

Analyses were also conducted on student responses to their self-perceived communication ability and average scores on the MCT and MRT tests. As there was a lack of student responses on the non-agreement end of the Likert scale (strongly disagree/slightly disagree, neither agree nor disagree), student responses were categorized into three types: non-agreement, somewhat agree, and strongly agree. T-tests between the average scores of the MCT and MRT and students’ self-reported ability was conducted only on somewhat agree and strongly agree categories. Table 1 provides descriptive statistics of the data gathered from the spatial and verbal analogy testing.

Table 1. Means (standard deviations) on spatial and verbal analogy tasks

	Domestic		International	
	Male (n=39)	Female (n=27)	Male (n=35)	Female (n=6)
Mental Cutting Test (MCT) 25 pts possible	11.72 (std dev=5.63)	9.74 (std dev=4.59)	8.37 (std dev=4.45)	7.17 (std dev=4.67)
Mental Rotation Test (MRT) 24 pts possible	17.13 (std dev=5.69)	14.85 (std dev=6.02)	13.09 (std dev=5.27)	14.17 (std dev=3.49)
Verbal Analogy Test 16 pts possible	9.54 (std dev=2.5)	9.26 (std dev=2.35)	8.29 (std dev=2.32)	7.67 (std dev=1.37)

3 RESULTS

The data was tested for normality and was found to be normal except for the male domestic mental rotation test scores. Table 2 reports the results from the normality testing. In addition, tests of equal variances (H_0: $\sigma_1^2 / \sigma_2^2 = 1$) indicated that equal population variances could be assumed when performing t-tests. Table 3 reports the t-tests results for between groups based on student status (domestic or international) Table 4 indicates the t-test results for between groups based on gender.

Table 2. Tests for normality (p = 0.05)

	Domestic		International	
	Male (n=39)	Female (n=27)	Male (n=35)	Female (n=6)
Mental Cutting Test (MCT)	p-value: 0.475	p-value: 0.869	p-value: 0.063	p-value: 0.565
Mental Rotation Test (MRT)	p-value: **0.00075**	p-value: 0.288	p-value: 0.512	p-value: 0.092
Verbal Analogy Test	p-value: 0.407	p-value: 0.322	p-value: 0.321	p-value: 0.093

Table 3. Significance of t-tests between groups based on status (Domestic/International)

	Male		Female	
	Domestic (n=39)	International (n=35)	Domestic (n=27)	International (n=6)
Mental Cutting Test (MCT)	p-value = **0.006275**		p-value = 0.2244	
Mental Rotation Test (MRT)	p-value = **0.002316**		p-value = 0.7914	
Verbal Analogy Test	p-value = **0.02918**		p-value = 0.1218	

Table 4. Significance of two sample t-tests between groups based on gender (Male/Female)

	Domestic		International	
	Male (n=39)	Female (n=27)	Male (n=35)	Female (n=6)
Mental Cutting Test (MCT)	p-value = 0.136		p-value = 0.5459	
Mental Rotation Test (MRT)	p-value = 0.1238		p-value = 0.6323	
Verbal Analogy Test	p-value = 0.6491		p-value = 0.532	

No differences by gender were observed but this could be attributed to the fact that all participants, both male and female, practiced spatial thinking skills development as part of their first-semester course. The results of our analysis revealed that the only significant differences in all groups was between Male Domestic and Male International students on all three tests. Tables 5-8 report a comparison of the average scores of the MCT and MRT tests to students' self-perceived communication abilities (Q1-Q4).

Table 5: Students' self-reported ability to assemble furniture given instructions (Q1) vs. averages on spatial test scores

Response Rating (n=110)	Non-agreement (n=4)	*Somewhat Agree (n=15)*	*Strongly Agree (n=91)*
Average score on Mental Cutting Test (out of 25)	12.75 (51%)	9.2 (37%)	9.82 (39%)
Average score on Mental Rotation Test (out of 24)	18.75 (78%)	13.66 (57%)	15.28 (64%)

T-test results indicated no statistically significant differences in the average scores between students who reported somewhat agree and strongly agree to Q1 on both the MCT ($t = 0.415$, $df = 104$, $p = 0.679$) and the MRT($t = 1.01$, $df = 104$, $p = 0.315$).

Table 6: Students' self-reported ability to create phrases or words for non-technical ideas (Q2) vs. averages on spatial test scores

Response Rating (n=110)	Non-agreement (n=5)	*Somewhat Agree (n=35)*	*Strongly Agree (n=70)*
Average score on Mental Cutting Test (out of 25)	9.2 (37%)	11.54 (46%)	9.04 (36%)
Average score on Mental Rotation Test (out of 24)	19.4 (81%)	16.02 (67%)	14.47 (60%)

T-test results detected a statistically significant difference in the average scores between students who reported somewhat agree and strongly agree to Q2 for the MCT ($t = 2.433$, $df = 103$, $p = 0.017$), but not for the MRT ($t = 1.316$, $df = 103$, $p = 0.191$).

Table 7: Students' self-reported engineering communication ability for non-technical audiences (Q3) vs. averages on spatial test scores

Response Rating (n=110)	Non-agreement (n=4)	*Somewhat Agree (n=44)*	*Strongly Agree (n=62)*
Average score on Mental Cutting Test (out of 25)	8.75 (35%)	10.32 (41%)	9.58 (38%)
Average score on Mental Rotation Test (out of 24)	14.75 (61%)	15.70 (65%)	14.85 (62%)

T-tests results indicated that no statistically significant differences in the average scores between students who reported somewhat agree and strongly agree to Q3 for the MCT (t = 0.7313, df = 101, p = 0.466) and the MRT (t = 0.769, df = 104, p = 0.443).

Table 8: Students' self-reported writing ability (Q4) vs. averages of spatial test scores

Response Rating (n=110)	Non-agreement (n=8)	*Somewhat Agree (n=40)*	*Strongly Agree (n=62)*
Average score on Mental Cutting Test (out of 25)	8.625 (35%)	10.45 (42%)	9.61 (38%)
Average score on Mental Rotation Test (out of 24)	17.5 (73%)	14.33 (60%)	15.45 (64%)

Final t-test results also indicated no statistically significant differences in the average scores between students who reported somewhat agree and strongly agree to Q4 for the MCT (t = 0.807, df = 100, p = 0.422) and the MRT (t = 0.963, df = 100, p = 0.338). Suprisingly, students who reported lower self-perceived communication abilities often had higher average scores on the spatial tests. However, the number of participants in the non-agreement category is small across all four questions.

4 SUMMARY AND ACKNOWLEDGMENTS

This work was completed as part of a larger research study that aims to explore a potential linkage between spatial and technical communication skills. An online survey was administered that consisted of two validated spatial visualization tests (Mental Cutting Test / Mental Rotation Test), a verbal analogy task, and questions regarding students' self-perceived communication ability. Results identified statistically significant differences in test scores between male domestic and male international students on all three tests. Interestingly, no gender-based differences were observed. Average student scores on the two spatial visualization tests were compared with students' self-perceived communication ability. Statistically significant differences were found on the average scores of the Mental Cutting Test between students who somewhat agreed and strongly agreed that they are confident in their ability to generate appropriate words or phrases about non-technical ideas. Interestingly, it was noted that students who reported lower self-perceived communication abilities often had higher average scores on the spatial tests. Future data analysis includes technical documents that participants created as well as video-recorded participant responses to a variety of linguistic tasks. This additional data can help explore a potential link between spatial and technical communication skills and allow for more direct measures to be developed targeting communication ability.

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Preparing Structural Engineering Graduates to Increase their Positive Impact

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ABSTRACT

Traditionally the role of a structural engineer was to design structures that were safe for use by society and that enabled society to develop and evolve. However, with the climate emergency structural engineers need to be more conscious of the choices that are made on their projects that lead to overuse of material, and work to reduce the embodied carbon in their structures. This cannot be achieved in isolation, it’s a systemic issue, where decisions made throughout a project, from concept to construction, can impact the embodied carbon. The structural engineer needs to be mindful of these decisions to have a greater positive impact on construction projects. It may be due to how the project is specified, how it is designed or how it is constructed but the result is the same, the structure exceeds its functional need, it is overdesigned.

This research investigates, through 14 interviews, why overuse of material occurs on construction projects, specifically buildings, and what the first steps to change could be. This research outlines how some of these first steps include the knowledge and attitudes that are first developed in students within their early years of engineering education. This research aims not only to identify the messages we are giving to students but also to aid educators in recognising the other challenges that young graduates will be faced with. By developing educational programmes to equip individuals with the necessary skillset and knowledge, they can actively challenge traditional attitudes and become vital advocates for change.

1 INTRODUCTION

The construction industry is responsible for nearly 40% of global energy-related CO_2 emissions (Gibbons et al. 2022; J. Orr et al. 2021). As engineering professionals, we have a crucial role to play in reducing our impact on the environment. While efforts have been made over the last few decades to improve the energy efficiency of buildings and reduce operational carbon emissions, the embodied carbon from the structural elements has become a much larger proportion of the overall building carbon than before (J. Orr et al. 2021). To address this issue, all stakeholders in the construction industry must take action to reduce the embodied carbon in buildings.

Meadows (2008) highlights the importance of "leverage points" in the system where a small change can lead to a significant shift in behaviour. The education of professionals in this industry is a leverage point. The education of structural engineers is a significant part of this, not just their technical understanding, but their ability to impact positively on the change that is needed in the sector.

Unfortunately, the overuse of materials is a prevalent practice in structural engineering, as supported by the MEICON report based on a survey conducted in 2018 (Orr 2018). The underlying reasons for this tendency will be explored further in this paper through the analysis of interview responses. While design standards exist to prevent inadequate design, there is often no defined upper limit for the amount of material used. While there may be constraints due to budget or space, things are often built with more material than necessary without any penalties or defined limits.

However, the material used in construction can be refined, and this paper presents research conducted as part of a PhD study on understanding overuse of material in structural engineering projects. Through interviews with industry professionals, this research investigates how they perceive the culture of overuse and how it can be changed.

2 METHODOLOGY

2.1 PhD research

This paper presents a preliminary exploratory phase of a PhD research project that examines the attitudes and perceptions of construction professionals towards the overuse of materials in structural engineering, with a particular focus on new buildings. Rittel and Webber (1973) coined the term "wicked problem" which is related to social issues that cannot be solved with science. Blockley and Godfrey (2017) use the term to describe the challenge of changing the culture within the construction industry due to the number of people involved. They list clients, designers, contractors, customers, governments, regulators, and the general public, but to address the wicked problem of material overuse in construction, educators can also be added to this list. To positively impact the overuse of material in construction, it is essential to understand the complexities of the system, and how the aims and objectives of any one part can influence the design, and ultimately the embodied carbon of the building. By exploring the perspectives of different individuals involved in the construction process, this PhD research aims to highlight the challenges and identify potential strategies to promote sustainable construction practices and address the overuse of material in the industry. This paper particularly focuses on the role of education for structural engineers in addressing these challenges.

2.2 Sample Identification

For this research, a total of 14 individuals were selected for interviews based on the criteria of "personal involvement" and "external cues" (Mauksch, von der Gracht, and Gordon 2020). Specifically, participants were chosen based on their personal involvement with embodied carbon research and/or professional engineering bodies (P1-P8, P12, P13), the length of their career (P9, P10), or for a contrasting perspective to other participants (P14). The final group was chosen as a representative of a more traditional consultancy that has remained active in the industry in recent years, in contrast to the first two groups of forward-thinking individuals or partially/wholly retired engineers with a good perspective of traditional viewpoints but less active in the industry since the declarations of climate emergency (BBC 2019a, 2019b). All participants are qualified engineers based in the UK or Ireland. Although the findings are biased towards the need for change and the viewpoint of the structural engineer, this is not considered problematic, as the goal was to utilise the expertise of these individuals to establish a foundation of viewpoints on causes, challenges, and potential solutions to overuse of material during design and construction.

2.3 Ethical Approval

Ethical approval was obtained from the University of Bristol Faculty of Engineering Research Ethics Committee [Ref: 10703] before conducting the interviews. Participants were fully informed of the study's purpose, data confidentiality and storage, and their right to withdraw. Written consent was obtained from all participants.

2.4 Interviews

A semi-structured interview approach was used, offering focus and flexibility during the conversation. For example, to capture the diverse perspectives and nuances surrounding the term 'overdesign', participants were not provided with a predefined definition, allowing them to express their understanding based on their experiences. This method proved suitable for the exploratory phase of the research, enabling in-depth exploration of the topic's breadth and depth. Interviews were conducted both online and in-person in Summer 2022, lasting 45-60 minutes. Participants shared their backgrounds and discussed their views on 'overdesign', the reasons it occurs, and solutions to promote refinement. For confidentiality, participants are labelled P1 to P14.

2.5 Interview Analysis

Interviews were transcribed using AI transcription software and manually verified. Transcriptions were analysed and coded to establish common themes. In the results, quotes may be edited for clarity, while maintaining context, with omissions marked by three dots (…).

2.6 Defining Overdesign

Before analysing the interviews, it is important to define 'overdesign' for this study. Orr et al. (2021, xiii) describes it as "overly conservative design of structural elements", which is subjective. This paper adopts P3's definition: "using more material than is actually needed to meet the desired outcomes of what the client is asking for". P2 further contributes to this understanding stating: "Maybe it's not just over design, and over-specifying, and over-demanding from an architect, but it's over building from a contractor, as well”. This shows a distinction between over design by the structural engineer for their own purposes and ‘overdesign’ that results in more material used than needed for the “desired outcomes”, that distinction being that the latter includes the former.

Notably, P3’s definition includes the concept that a new construction project may not be necessary. P5 points out that “if you're designing something that's new, anything that's new, you could argue that you're already in the world of overdesign because the first thing you should do as a designer is try not to build anything at all”. While avoiding a need for new construction offers significant carbon savings, the PhD research focuses on new builds to explore leverage points throughout the construction process for promoting a culture of refinement.

Throughout the interviews, it was evident that the term ‘overdesign’ evoked defensive responses or suggestions for alternative terminology from participants, based on their prior experiences. Considering this, it is important to clarify that this study aimed to explore efforts that can positively influence climate targets by reducing material usage and increasing design efficiency. As a result, future phases of this PhD research will strive to employ more positive language, moving away from the term ‘overdesign’ to allow for a more constructive discussion. Therefore, while the use of the term ‘overdesign’ is limited in this paper, it was employed during the interview process. It is worth noting that using this term with students may have certain benefits, as a negative term can potentially contribute to the development of responsible behaviours.

3 RESULTS

3.1 Overuse in the Construction Industry

To prepare students for their role in reshaping the culture of material overuse in the construction industry, it is crucial to understand the definition and underlying reasons for overuse. The interviews highlighted several themes associated with overuse, including high imposed loads, counterproductive layouts, low utilisation, high rationalisation, rationalisation of geometry, higher concrete grades, and oversized excavations. These concepts can be understood in non-structural engineering terms, such as designing for excessive occupancy, incorporating long spans or inconsistent column positioning, underutilising element capacity, maintaining uniform element sizes regardless of load requirements, employing consistent rectangular cross sections, using excessive cement in concrete mixes, and excavating larger foundations than necessary. While this list provides a contextual snapshot, it does not encompass all aspects of the problem.

To categorise the reasons behind material overuse, this paper adopts a simplified framework based on the construction process’s four key stages to handover: brief, concept, design, and construction. It is important to note that stages beyond handover, i.e. use and end-of-life, were not extensively discussed in this research phase.

During the brief stage, requests may include elements not necessary for achieving the desired outcomes. For example, a higher load may be specified due to client expectations regarding rentability: “They find it easier to rent an office block that has a capacity of 5 kN/m^2 as opposed to 2.5” [P12]. Budget and programme constraints often shape decisions during this stage, with designers expressing the need for more time to refine their designs but that time means their budget needs to be increased: “It's not in our control… if people were given more time to design… and time… equates to fees.” [P14].

In the concept stage, the focus is often on “very long spans…or… complicated transfer structures” resulting in “the structural function coming second to other things” [P3] as opposed to the other way. “If nature was designing these buildings you would end up with form follows function” [P3]. At this stage the structural engineer is often not involved, with the view that “the architects lead designers will generally be there and understand these conversations and take that back to the team” [P12].

The primary reason for overuse in the design stage “is based around reducing risk” [P2], meaning designers are reluctant to push utilisation factors to 100%. There is “a belief that somewhere else in a supply chain, we’re going to have incompetence” [P6]. A preferred utilisation value of 80% was frequently mentioned by participants, as it aligns with findings from the MEICON report (John Orr 2018). Designers often add extra material to future proof against “all the potential for change, which you know, is going to happen down the line” [P6].

The construction stage significantly influences design decisions. Ease of construction becomes a priority for the programme, leading to high levels of rationalisation. This results in an additional reduction in utilisation throughout the structure. This issue was raised by several participants and also supported by research (Moynihan and Allwood 2014). “Trust in the construction quality” [P7] is also a contributing factor. For example, P7 stated: “If you have definitely seen poor construction practice you might want to add a bit more bunce in there”. Bunce is a term used in some parts of the UK to account for an additional safety factor provided by an engineer just to be sure. The extra magnitude is poorly defined but results in a lower utilisation ratio.

On-site decisions also impact material overuse. Contractors may specify higher-strength concrete mixes because “they’re going to pump 50 metres along the way, which means it’s got to be stronger concrete, or they’re wanting flowing concrete or self-compacting concrete, which means you need to have more cement in it” [P8].

3.2 Preparing for Change Through Education

In the past, the mantra of “if in doubt, build it stout” [P10] guided structural engineering design, prioritising robustness. However, to address the carbon impact of new buildings, this approach must be challenged, and a focus on reducing material use needs to become commonplace. Alongside a personal and professional desire to reduce the overuse of material, to eliminate a “sleep at night factor” [P4] it is essential that designers have confidence in the system which includes the accuracy and finality of the information they are provided, the quality of fabrication/construction, and the appropriateness of use. This not only requires an awareness of the problem but a combination of technical expertise to refine designs, and effective time management and communication skills to foster a collective commitment to carbon reduction.

Climate Agenda

The primary reason for the overuse of material in construction is tradition, it’s cultural, it’s systemic, “it’s instilled in lectures in first year… it's absolutely prevalent, right from the first day, first year of an education to be a structural engineer” [P6]. Therefore, the first step to change, within education, is for educators to acknowledge the messages that they embed that contribute to the culture of overuse of material. At a minimum, this means a ‘didn’t know better’ excuse won’t continue, and no longer will engineers be able to say that “nothing told me that I needed to dig into this. And maybe because the institutions weren’t, my clients weren’t, my architects weren’t. I let myself go with the flow” [P2].

A personal drive to change can be developed through awareness and exposure during education. A “personal positions on climate emergency are crucial to drive each one of us” [P2]. Educators can “encourage young engineers to find their agenda for every project… if you have no agenda, you just float with other people’s agenda and just follow… if you haven’t got that agenda, you’re having no impact” [P2].

Technical Skills

Imposed loads emerged as the most frequently mentioned form of overdesign in the interviews, highlighting its significance as a starting point for developing the technical skills of structural engineering graduates. Participant P1 emphasised graduates should “have a much better understanding of what a kN/m^2 looks like and how realistic it is”.

While design codes serve as a safety baseline, they can be overly conservative, as P5 points out: “The codes are so conservative… if [designers] understand the performance issues better, you can change the serviceability factors, some of which are not mandatory, there are partial factors you can play around with”. As a result, structural engineering students must become well-versed in design codes and the origins of these factors, as well as their conservative nature. This knowledge will enable “engineers to design closer to the bone” [P5].

Understanding the code and the partial safety factors can lead to the development of an understanding of how structures fail and the difference between mean strength and characteristic strength. By exposing students to testing in laboratories and observing failure, they can see “when something fails, by definition, it mobilises its mean strength, by definition, it has to because it has to happen over a large surface area for any failure to occur, not the characteristic strength, and there's a gigantic difference between the two” [P6]. If students can be educated to see that designing “to the bone is massively safe” [P6] and “normally when they fail, it’s not because of a failure of an individual component, it’s usually a failure of a connection or… it’s a gross misunderstanding of structural behaviour, neither of which come from code” [P4].

To reduce the risk of changes to designs from site, structural engineers need site experience to develop an awareness of constructability. Sometimes “if you're a young graduate, and you're employed by a firm or consulting engineers … there's not much of an opportunity to get out and do your site experience” [P9], so it is important to include some level of experience within the university curriculum, either through site visit and/or work placements. Thereby ensuring that the refined designs that are created are unlikely to be modified on site for ease of construction. Additionally, knowledge of how things are constructed will guide the use of realistic specification requirements to avoid putting “something in a specification that’s impossible” [P2]. For example, unrealistic tolerances can result in elements of work being redone as tolerances weren’t met or replaced due to cracking, ultimately an unnecessary waste of material.

While understanding advanced structural behaviour, i.e. vibration, catenary action, secondary effects, tensile skins etc, was discussed by some participants it is not developed further in this paper as it is less likely to be commonplace at the undergraduate level.

Soft Skills

Since material overuse is impacted by numerous decisions throughout the construction process, an individual’s technical ability alone won’t drive industry-wide change. While it can lessen the individual's impact, softer skills are needed to transform the system. These are skills outside the technical

In the modern digital era, time constraints play a significant role in the design process. With meetings being held online and drawings no longer physically posted, the time available for reflection and idea generation is significantly reduced. “Time spent on allowing people to mull ideas over is a really important aspect of trying to not overdesign” [P7]. Therefore, it is crucial to develop students’ time management skills to prepare them for the demanding time requirements of the industry. This includes allocating time for reflection, review, and embracing feedback cycles as valuable components of the design process.

Structural engineers play a crucial role in advocating for sustainable design decisions. They first need to advocate to be included in discussions that affect the brief and the concept. Then they need the tools and confidence to speak up in these meetings and provide valuable input on decisions that affect the design efficiency. As P7 stated: “giving them the tools to feel empowered in speaking up about putting a column there or reducing your grid or maybe don’t have that heroic cantilever”. This skill will also allow engineers to advocate for design freezes, to tackle the need to future proof for fear of change. By developing their confidence and providing them with diplomatic communication skills, students can become advocates for sustainable and efficient concepts that allow a refined design.

Communication dynamics differ when engaging with different stakeholders in the construction industry. While discussions with stakeholders during the brief and concept stages often involve individuals who share a formal higher education background, interacting with construction operatives requires a different set of communication skills. P9 speaks from personal experience, describing the challenge of conveying information to construction operatives who may not have formal education or strong literacy skills. They emphasised the difficulty of communicating complex ideas, stating, “I do a lovely set of drawings; he’s not even looked at them... I’ve even stood there with him... and he doesn’t understand what I’m talking about. ... So, conveying information to the people who are implementing it is very, very difficult.”

To overcome these challenges, students need to develop communication skills that encompass clarity, empathy and collaboration, while maintaining assertiveness. They should use straightforward language, avoid technical jargon that others may not understand, and break complex instructions into manageable steps. Additionally, they should demonstrate empathy by appreciating and respecting the skills and expertise of construction operatives. Collaborative communication is crucial, allowing for feedback and a better understanding of what can and cannot be achieved on-site.

However, assertiveness is still required to ensure that the quality control required to design efficiently is maintained on site. This may mean a “bit of tough love… to just get people thinking the right way, and they [the contractor] need to know that they're under scrutiny” [P9].

The dynamics between design and construction make this a complex communication arena where very good verbal, written and graphical communication skills are required. The importance of this skill set is represented by its inclusion in accreditation criteria for engineering programmes (JBM 2021). Ensuring this skillset, already in the curriculum, is adapted to deal with these efficiency conversations would prepare the students for implementing positive change within the industry.

4 DISCUSSION AND CONCLUSIONS

The overuse of material in structural engineering projects is a complex issue, which starts within education and continues throughout careers in industry. There is no single straightforward solution to moving towards a more efficient and sustainable construction process. However, addressing this challenge is essential to reducing the embodied carbon of buildings and achieving global climate targets. From educators to senior structural engineers, the message that is traditionally passed to the next generation of structural engineers is one of wastefulness. This message needs to change, and it needs to change from day one of a structural engineer’s exposure to the industry, for most students this exposure begins in the lecture theatre. For students with previous engineering exposure, day one of university is still an opportunity to reset, an opportunity to reshape their existing mindset at this key transitional stage of their careers.

Education can make a significant impact by developing a structural engineering students’ knowledge of the importance of using less material and where savings can be made. These savings can come from a deeper understanding of the design codes, loading and constructability. By developing their technical ability to design structures with greater efficiency and ensuring that their designs are constructible, structural engineers can play a vital role in shaping a sustainable future within the industry. For a greater impact, students need to have the ability to communicate with other stakeholders on either side of the design phase to have projects where efficiency is a common goal and quality assurance is essential.

By encouraging a new generation of engineers equipped with the knowledge, skills, and confidence to challenge traditional practices, engineering education can contribute to the positive impact these structural engineering graduates can have in reshaping the construction industry towards a more sustainable and efficient future.

This PhD research will advance by focusing on key roles in the construction system and expanding participant selection from the industry. A randomised approach will capture a realistic view of cultural change in new builds, informing strategies to reduce material usage and promote sustainability.

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A FRAMEWORK FOR A SCOPING REVIEW OF DIGITAL TRANSFORMATION OF ENGINEERING EDUCATION

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ABSTRACT

The digitalization of engineering education has made significant progress in recent years not only due to societal circumstances such as COVID-19, but also thanks to technological development and progress and digital transformation of engineering education seems more imminent than ever. This paper presents the development of a framework and process for an ongoing scoping review regarding frameworks for digital transformation of engineering education. Empirical studies on digital innovations in specific small-scale contexts are numerous and the literature is rich. This study, however, aims to identify more systematic and holistic approaches to digital transformation. At this stage the review work has resulted in 21 research papers for full-text screening from 4 databases, SCOPUS, ProQuest, Web of Science, and Engineering Village. The proposed framework facilitates analysis of how frameworks for digital transformation of engineering education are informed and conceptualized ideologically in the sense of what digitalization should do for engineering education and how they guide and facilitate digital transformation. The framework builds on and combines theory from educational and digital transformation research and enables elicitation of essential elements of digital transformation in an educational context, including ideologies, models, dimensions, actors, elements, and levels of digitalization.

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1 INTRODUCTION

The promise of an imminent digital transformation (DT) of engineering education, and higher education, has lasted several decades at this point. In many ways we *have* digitalized practices in higher educational institutions at an organizational level, but when it comes to transforming education many of the potentials of digital technology are yet to be realized. Empirical studies on digital innovations in specific small-scale contexts, such as the classroom, are numerous and the literature is rich. In contrast, this study is interested in more deliberate, informed, or ideological approaches to digitalization asking and answering what digitalization should do for education and how. All the way back to 2007, Laurillard (2007) wrote that digital technology has merely been consigned to support traditional modes of education. This is to a large extend still true today. A blind eye has been turned to the transformational potential that digital technology can have in realizing the educational ambitions we have. In most cases digitalization of education has merely supported or replicated traditional modes of education. In this connection, some studies (e.g. Figlio et al., 2013; Shu & Gu, 2018) have found digital education inferior to traditional by e.g. comparing students' experiences of face-to-face lectures with online versions. Weller (2022) calls such comparisons and findings unfair and unsurprising. It is like comparing the live performance of theatre to seeing it on television. This type of digital education suggesting a 1:1 transfer of traditional pedagogy to digital versions has been especially prevalent in recent years of emergency remote teaching due to COVID-19 (Mseleku, 2020) for many reasons. For actual DT of education, and to avoid drawbacks of the 1:1 transfer, we need to move past digital replicas of traditional education and experiment with and explore the potentials and affordances of more native digitally and hybrid designed education. Such an approach might help us in realizing some of the many promises of DT and the ambitions we have for engineering education. The technology for DT is mature and ready – are we?

This paper will present the process and development of a framework for an ongoing scoping review that aims to uncover the body of literature within engineering education research that can help us take such steps i.e., systematic, and holistic approaches to DT of engineering education. By combining educational research with Kræmmergaard's 5-stage DT model (Kræmmergaard, 2019), the framework will enable us to identify relevant frameworks of DT and classify the type of transformation and level that they aim to facilitate.
The framework helps to elicit answers to how frameworks for DT of engineering education are informed and conceptualized ideologically in the sense of what digitalization should do for engineering education and how they guide in terms of how transformation can be facilitated.

2 METHODOLOGY

The research objective of this paper focus on examining frameworks for DT of engineering education including their key characteristics. For such a purpose, Munn et al. (2018) suggest the scoping review as the most appropriate. Scoping reviews differ from systematic literature reviews in that the latter typically seek to answer precise questions, with defined methodologies (O'Flaherty and Phillips, 2015), whilst the former has a more exploratory purpose of e.g., clarifying key concepts, examine how research is conducted on a specific topic or field, or to identify key characteristics related to a concept (Munn et al. 2018). Often scoping reviews are utilized in preparation for an actual systematic literature review to determine whether a complete systematic review is necessary (Munn et al., 2018; O'Flaherty and Phillips, 2015). In this connection, scoping reviews may help to develop and confirm e.g., relevant inclusion criteria and analytical themes in relation to a specific concept, which is also the purpose of this paper presenting the framework of the scoping review.

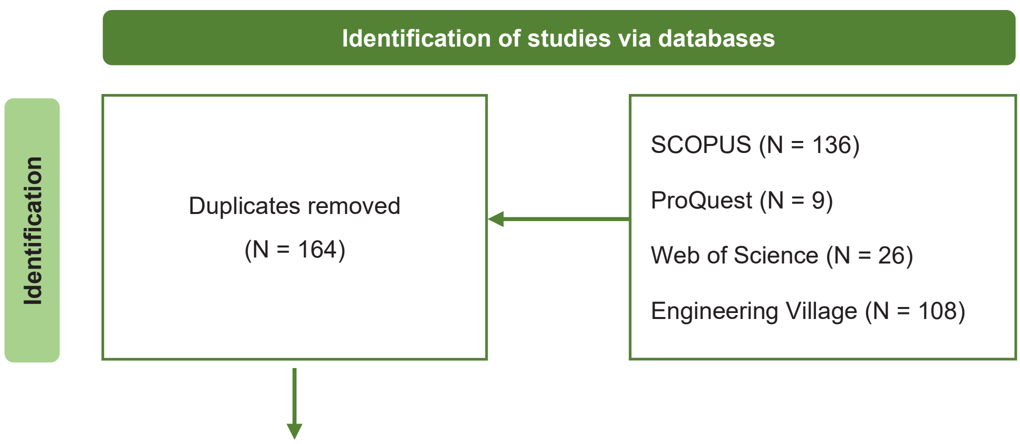
Based on the aim of this scoping review a set of criteria for inclusion was developed. (1) Selected research must be peer reviewed and either of the type of conference paper or journal article and written in English. (2) The context of the research must be within engineering education. (3) The research must have an educational and/or pedagogical focus. (4) The paper must present a clear framework for DT above classroom level. This set of criteria guided the reviewers screening. The included databases count SCOPUS, ProQuest, Web of Science, and Engineering Village. The final search string that was executed March 2023 can be seen in table 1 below.

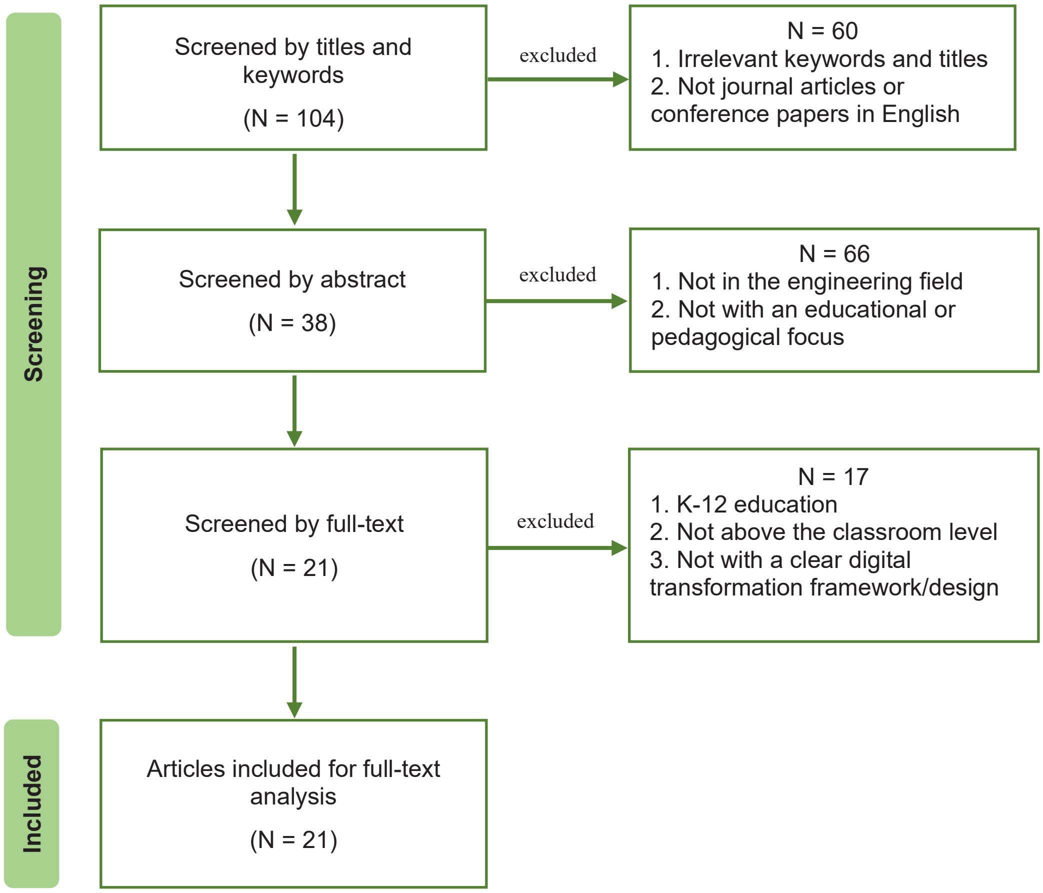
Table 1

"engineering education*"	AND	Digital transform* OR Digitally transform*	AND	Framework* OR Model* OR Design*

As can be seen from the PRISMA chart in table 2, the search result produced 164 items for further screening after removal of duplicates across databases. Screening was initially based on title and keywords, which excluded 60 items, and then secondly based on abstract, which removed further 66 items. Finally, a full-text screening excluded an additional 17 items. In the end, a total of 143 items were deemed irrelevant and excluded for various reasons related to the inclusion criteria as can be seen in the PRISMA chart. For each step in this process, the authors ensured a common understanding by random control checks of the same papers and thereby minimizing researcher's bias (Munn et al., 2018). This resulted in a pool of 21 papers which will undergo full-text analysis in the final review.

Table 2





3 THE FRAMEWORK AND PRELIMINARY RESULTS

3.1 The framework

This section will describe the development of the analytical framework. First, as a central concept for the review, a definition of DT is important, which will be followed by the analytical themes of the framework.

Kræmmergaard (2019) developed a 5-stage DT model for industry and public institutions, that describes the most basic implementation of IT at stage 1 to full DT at stage 5. This classification is essential to the analysis of the identified frameworks and will therefore be shortly presented in the following. We will contextualize the stages to DT of engineering education by adding examples to Kræmmergaard's work.

Stage 1 and 2 is popularly described as electrifying existing work practices and processes for the purpose of efficiency and economy gains. At stage 1 support of existing practices and services with IT is key. Digital technology has a supportive role and allows users to help themselves by e.g., accessing supporting material or finding the class schedule in learning management systems. At stage 2 there will be a standardization of systems. Digitalization strategies are formulated centrally at the leadership level and focus is on implementing new technology for the purpose of streamlining. Work practices and processes still need to adapt to technology rather than the other way around. An example of this could be during COVID-19 lockdowns, where various digital tools, e.g., tools for video conferencing and online whiteboards, quickly became standardized, and teachers had to adapt practices to those platforms with all the constraints that follow. From stage 3 and up, digital technology is a central part and co-creator of the educational practice and experience. Focus is on rethinking core practices and processes in a digitally native manner. Digital replicas of e.g., face-to-face lectures using Zoom are no longer enough. At this level, staff and students need to explore and take advantage of the new affordances that digital technology can provide. Stage 4 is where the organization will challenge itself to rethink its own core services through digitalization. Previous assumptions of what "good" education should be are challenged. There is a seamless integration of systems, which could be used for e.g., collecting learner analytics and create more personalized learning experiences. At stage 5, technologies such as AI, machine learning and AR/VR are widespread and well-integrated to search for and create new patterns and opportunities in combination with human decision making.

To guide the coding and analysis we, the authors, discussed initial themes based on the aim of the review and Kræmmergaard's framework, which were then shared and discussed with colleagues in our research group. The final pool of papers included in the review are to be mapped and analyzed according to this codebook with different themes. For mapping purposes demographics categories were also created. This process resulted in the codebook seen in Table 4 below filled in with information from an example of a random paper from the current pool of 21 papers.

Table 3

Country	Year	Type of publication
Moldova	2021	Conference proceedings

Discipline	Level of education	Stated pedagogic model(s)	Digital tools	Level of educational organization	Digitalized learning activities/elements	Educational/ pedagogical focus	COVID-19 reaction
All engineering disciplines	All semesters	Distance education	Remote and simulation labs, Teams, Moodle, online video platform	Institutional	Remote lab, simulation lab, interactional analytics, assessment activities, LMS, online video lessons.	Yes	Yes

Underlying drivers and/or ideologies	Framework focus	Clear, guiding, holistic framework?	Organizational levels involved and actors	Digitalization form	Level of digital transformation
Risk mitigation (against lockdowns), employability, marketization	Entangled	Yes	Institutional level	Content, cognitive, emulation, interaction, creation	Gen. 4

Some of the themes are descriptive and answers are easily elicited from informational text in the papers. This is true for the first row of table 4, colored lighter shades of green. They include demographics information for mapping purposes, i.e. *country; year;* and *type of publication.* Second row, green color, include contextual information such as *discipline; level of education; stated pedagogic model(s); digital tools; level of educational organization; digitalized activities/ elements; use of pedagogic or educational research; and COVID-19 reaction (whether the DT happened during or as a response to COVID-19 lockdowns).* These themes will mainly answer the "what-, when- and where-questions".

The remaining themes in the third row require holistic analysis to elicit an answer from the text, either because it is not clearly stated, or because a higher level of complexity. These are colored in dark green and include the themes *underlying drivers and/or ideologies (UDI); framework focus (FF); clear, guiding, holistic framework (CGHF); organizational levels involved/actors(OLIA), and type of digitalization (TD)*. The *UDI* theme will elicit values and beliefs underlying actions towards DT. Examples could be employability, marketization, accessibility and inclusion, reducing vulnerability (e.g. to lockdowns), better learning gains, sustainability etc. *FF* can either be technological, pedagogical or entangled. Fawns (2022) described how discourses and implementations of digitalization have been plagued by deterministic ideas, where either technology or pedagogy are dominant. This might be reflected in frameworks for DT. Fawns advocate for an entangled understanding, recognizing that technology and pedagogy cannot be handled as separate, isolated phenomena. This is also central to the upper-levels of Kræmmergaards's framework, where digital technology is no longer regarded as supplementary but as integrated and entangled with general practices and processes. *CGHF* is an important theme in terms of the possibility of analyzing the intentions and scope of the framework. In relation to this, *OLIA* will report roles and actions by different actors in different organizational levels. In relation to the Kræmmergaard framework, this is important, as she describes DT develops from being localized, to centralized, and finally more towards decentralization through the stages. Finally, TD will capture different types of digitalization, divided in digitalization of content, cognitive facilitation, emulation (VR/AR), interaction, and creation (e.g. AI). These are based on basic affordances of learning (Chi, 2009; Laurillard 2013) and Kræmmergaard's description of advancement in the use of complex technology throughout the stages.

Together, the themes give data for a holistic qualitative analysis to answer the "how- and why-questions" of DT processes, i.e., why we choose to transform engineering education through digitalization and how engineering education is transformed through digitalization. It will also be possible to classify the level of DT that each framework aims to facilitate based on the Kræmmergaard framework.

The current themes will guide the initial coding and then be summarized together with themes that emerge through the open-coding method (Creswell, 2012) for further development of the framework.

4 DISCUSSION AND SUMMARY

The basic assumptions of how DT can be facilitated, and for what purposes we pursue DT, take part in forming the future of engineering education. However, institutional strategy documents, providers of digital technologies and other stakeholders rarely declare understandings, ideological drivers, or value statements in relation to DT, which makes it challenging to deduce the logics and drivers of DT. Thus, it is not always apparent how frameworks of DT are informed and imply specific understandings, purposes and directions for education. By interrogating frameworks of DT using the presented framework these will become more visible and comparable enabling stakeholders to have more informed reflections and decision processes. Furthermore, the adaption of Kræmmergaard's framework enables identification and description of certain indicators and enablers of DT and general characteristics of stage 3 and above transformations in a higher educational setting. It will be of interest to analyze future results regarding what are the drivers of such DT frameworks, the digital technologies implemented, and the types of digitalization in relation to learning.

This paper has presented the process and development of a framework for an ongoing scoping review of DT of engineering education. The search strategy and current screening process have resulted in 21 full-text papers for full-text analysis. The framework conceptualizes DT in an engineering education context based on educational and DT research and will generate rich data to create a state-of-the-art overview of DT frameworks within engineering education. The framework can be of use, or inspiration, for studies in other educational contexts as well and findings could be compared and discussed with other reviews of DT in higher education to single out unique traits of engineering education.

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Varieties of Project-Task Design in Interdisciplinary Engineering Education

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***Keywords**: Interdisciplinarity; project-based learning; challenge-based learning; problem-design*

ABSTRACT
Experience in interdisciplinary problem-solving is considered crucial if engineers are to be equipped to handle modern complex environmental and sustainability challenges. Such challenges cross disciplinary boundaries. Project-based learning is currently a central paradigm for providing that experience. Teams from different disciplines are formed to work together on a specific scientific or engineering project-task (often a real-world inspired problem). Furthermore according to the paradigm projects should be open-structured to allow students to experience interdisciplinary problem-solving as it might occur in the real world. In this study we explore preliminary results of data collected on 5 project-based modules at a Dutch technical university. We find that despite the preference for open-structure advocated in educational research the modules differ in terms of how structured they are, with the majority structured in a substantial way. In these cases the instructors design their project tasks to meet both institutional objectives and also to afford interdisciplinary interaction between students. We examine the motivations behind the design features they employ, and also some of the drawbacks based on student feedback. This study points the way to further research but should help build awareness of different design option and their tradeoffs.

1 INTRODUCTION

Interdisciplinary skills are widely seen as necessary for training real-world problem-solving abilities amongst engineers and scientists. In education, the development of such skills is often closely identified with project-based learning, and in turn, with projects designed around open-ended or open-structured problems [1],[2],[3]. Open-structured problems are meant to simulate authentic problems in which few constraints are set on potential solutions [4]. Students from different disciplines form interdisciplinary teams to find solutions to these problems. In the process it is hoped that students will develop skills relevant to working across disciplinary boundaries. Given the expectation that real world problems are generally not resolvable within current disciplines, students have incentives to experiment with new unfamiliar methods, and to acquire disciplinary perspectives outside their own, in order to fashion more optimal solutions [5]. At the same time interdisciplinary problem-solving is difficult, and open-structured questions can present real challenges to students who are not used to working together and for which problems are complex [7],[8].

Our preliminary investigation sought to answer the following research questions, 1) to what degree are projects in interdisciplinary project-based courses open-structured (given the prevailing view on open structured designs), and if not, how are projects designed; 2) what are motivations for various design steps with respect to supporting interdisciplinary education. To address these we investigated interdisciplinary project-based modules at a technical university in the Netherlands.

2 METHODOLOGY

2.1 Research Background and Questions

Open structrured or “open-ended” project tasks are problems designed with minimal constraints on how to interpret a problem, what methods to use to produce a solution, or what a solution should look like [9]. For such problems the problem-space is large, inviting many possible approaches and solutions. A central educational principle underlying PBL and PjBL (and CBL) is self-driven learning. Self-driven learning favors students having the responsibility for developing a solution to maximize their own ability to learn independently but also to think critically and reflect on their own knowledge and its limitations [5], [10]. There is a strong belief that real-world problems increases student motivation as a result [11].

Opposed to these are highly structured problems problems. These include many explicit or implicit constraints which narrow down the problem space, placing restrictions on which approaches to use, and funneling students towards only a small set of desired solutions. In between these two extremes lies a spectrum of designs each with varying degrees of structure. In an open-structured case, for instance, student teams may simply be asked to formulate a project task themselves in teams leaving it completely open how the problem is chosen and how it is formulated. Alternatively, specific project tasks may be presented by instructors or external parties, but still allow students to have control over how to interpret those tasks and solve them. In general, to qualify as open-structured, the task-descriptions should not seek to prescribe the approach students should take nor set strong constraints on a solution, or what the problem-solving process should look like [2].

Analysis on problem-design for either project-based or problem-based learning, interdisciplinary or not, is not extensive in general, at least in comparison to research on other aspects of project-based learning [12]. Nonetheless research has been done categorizing and framing the various considerations that should go into problem design generally [5], [13], [11]. Most substantive in this regard is the work by Hung and his collaborators to put together a holistic framework for problem-design in the context of PBL: the 3C3R framework [7], [11]. Within the 3C3R framework Hung and his collaborators suggest many important factors which govern problems over which designers have control. Interdisciplinarity is briefly mentioned in one paper as a factor of problem structure, but otherwise not considered by Hung nor to our knowledge in any other problem-design discussions.

2.2 Approach

To study these questions we have taken a case study approach; investigating five “modules” at a technical university in the Netherlands. This university’s core educational model is structured around project-based learning modules, consisting of multiple cohesive courses feeding into group projects. Some of these modules are interdisciplinary, i.e. that students from different faculties converge within the module, and work together in interdisciplinary teams for the duration of the project. Course and project design decisions are the responsibility of the instructors, such as whether to run the project over the duration of the quartile, apply it as a capstone, and which accompanying courses to implement.

Consumer Products (2nd year module): This bachelor module couples mechanical engineering, industrial engineering & management as well as industrial design students. 50% of the module is allocated to an interdisciplinary project-based design task, which is provided by an external client. Assessment is measured by the ability of the team to meet the external client’s requirements, as well as how they integrate knowledge from different disciplines.

Discrete Structures & Efficient Algorithms (2nd year module): This module pairs applied mathematics and computer science students. 20% of this module is allocated to a collaborative project at the end of the course. The project task is to produce an algorithm which can successfully test the isomorphism of certain graphs.

Modeling and Analysis of Stochastic Processes (2nd year module): This bachelor module involves students from applied mathematics , civil engineering , and industrial engineering & management . The module provides various sub-courses training students on various aspects of stochastic modeling, culminating in a final two week interdisciplinary capstone project called the “multidisciplinary project”.The goal is provide a hospital a schedule management systems, and result are assessed in terms of how effective and usable they are, but also how well components from different disciplines are integrated.

Autumn Challenge (open): The Autumn Challenge is an extra-curricular challenge-based learning elective, open to students of all disciplines affiliated with the European Community of Innovative Universities (ECIU). It is open to 3rd year bachelor and master students. Students collaborate across disciplinary boundaries on a challenge provided by an external party (e.g. business, government agency etc), and develop a solution through contact with the challenge provider, and the support of a tutor. Projects are partially assessed in terms of how well different disciplinary views are considered and synthesized in the result.

Science2Society (3rd year modules): Science2Society is part of the High Tech Human Touch minor programme; available to all students at the university. The minor programme allows students to take courses outside their bachelor programme in the first semester of the third year of their degrees. Similar to the Autumn Challenge, Science2Society students select problems provided by external groups (businesses, government agencies) to work in multidisciplinary teams. Students decide individually which challenge they would like to work on. Projects are also partially evaluated according to whether topics in multiple disciplines are explored.

For each case study we collected student survey data, semi-structured interviews with instructors, and course materials. In this study we rely particularly on course materials, which describe the project-task structure and criteria used in its assessment. Principally we examined project task descriptions and criteria collectively to assess whether any statement connected to the project set a constraint on what would be a good or valid project outcome or approach. Instructors were Interviewed on their design choices, to corroborate the intentions of such statements. Finally, we apply student survey data to reflect on aspects of those designs. For the Consumer Products, Discrete Algorithms and Science2Society this data derives from surveys we designed on students' interdisciplinary experiences and views on interdisciplinary education as a result. Students from consecutive groups were surveyed (2019/20 and 2020/21 groups). Response rates varied but track was kept of the disciplinary backgrounds of students and how frequently students from each discipline responded. Autumn challenge students were given a similar survey but just for the 2020/21 group. With respect to the Stochastic Processes module, we rely on standardized university course evaluation suveys from 2014/15 to 2017/18. These surveys included questions on interdisciplinarity and space for written feedback on interdisciplinary experiences.

3 RESULTS

3.1 Open-closed design elements

Of the courses we analyzed only the Autumn challenge task was purely open-ended in its design, meaning that interdisciplinary groups had the freedom to frame the problem they wished to solve (in consultation with a task provider); as well as how they would pursue it, what kinds of tasks they would each perform and what solutions would look like. The other modules employed a mix of structural elements in their project-task design; goal structuring, process structuring, problem balancing and modularity. They did so for a variety of reasons; at least partially to facilitate interdisciplinary interactions between their students, ensure constructive alignment. Table 1 describes the distribution of these design structuring elements.

Table 1. Types of structuring found in project based learning case studies.

Case study Structuring type	Autumn Challenge	Science 2Society	Consumer Products	Algorithms	Stochastic Processes
Goal structuring		✓	✓	✓	✓
Constraining problem-solving		✓	✓	✓	✓
Problem balancing					✓
Problem Modularization					✓

Here we describe briefly these types of structuring and their motivations:

Goal structuring: Most of our modules set specific constraints on the outcome of the project either through the description of the problem and its targets, or via the assessment criteria. An extreme example of this is the Algorithms module. The problem goal set for applied mathematics and computer science students to solve collectively was a specific graph isomorphism problem. This kind of problem requires teams to construct an algorithm which can correctly infer whether two graphs are isomorphic; a very particular well-defined goal.

A problem can be otherwise open-ended but still subject to this kind of structuring. In the Consumer Products module for instance the main task is somewhat an open-ended design task. The problems are given to students by clients to design a product based on a loose set of goals. These problems are supposed to be relatively open-ended in the sense that students can go in numerous possible directions based on their own assessments of what a good outcome should be. The module however does set some requirements on what the students need to produce, as well as how the design is to be evaluated, which naturally directs students towards looking at certain sets of solutions rather than others. Chief amongst these for instance is the need to have entrepreneurial or marketable design solutions. This constraint is not a neutral one. It narrows the sets of choices students need to consider.

Goal structuring was used according to course designers for a number of reasons in these interdisciplinary modules. Firstly, in the Algorithms and Stochastic Programming cases goal structuring was primarily a result of other institutional goals which needed to be taken into account for implementing interdisciplinarity in existing programmes. In these modules a primary goal was training students in specific mathematical and programming abilities required within their bachelor programs. As such the task needed to be designed to ensure students would exercise these abilities. Goal structuring was a means to channel students towards doing so. In certain cases however defining goals can direct students towards learning objectives that stimulate good interdisciplinary problem-solving, such as entrepreneurial skills for refining engineering design. In either case however the goal structuring serves to scaffold and direct interdisciplinary relationships towards specific goals rather than leaving it to students themselves to navigate.

Constraining problem-solving approaches: In addition to setting limits on what counts as a good solution, projects were also structured in our cases by limiting the "problem-space", namely constraining the set of methods and approaches students should consider. This included setting limits on the specific variables to be studied or by giving data of a particular kind. Some of these were introduced in the project-task context by training students in specific methods that could be practised and applied directly within the challenge. This is a feature of both the Algorithms module but also the Stochastic Processes module. In the latter the project forms the last two weeks of the module. Before that, students receive two courses in various types of mathematical methods. During these short courses students do small project tasks. Students are told that their answers can form the basis of their response to the capstone project. In this way students are guided in the set of choices and methods they need to consider in the design of the hospital waiting list management system. This kind of structure can be quite implicit however. The Science2Society case is framed by the instructors as open-structured problem-solving but the problems are nonetheless implicitly structured. One challenge given to students was to study how AI and big data can improve social housing. This question prioritized methods from computer science and gave priority to the capabilities of those methods.

As with goal structuring these design aspects play a dual role. They also direct students towards developing a specific set of skills, required by individual programmes, such as the application of algorithms to mathematical problems. In the Stochastic Processes case however these limitations were employed to reduce the challenges for students of finding an integrated interdisciplinary solution, given the instructors already had the desired solution in mind. Sub-tasks within the challenge, were designed to fit the skills and interests of participating disciplines. This did not preclude different methods being applied to each sub-task, nor how information should be precisely integrated but it did channel students towards a subset of the overall problem-space which contained integrable interdisciplinary solutions.

Problem balancing: The Stochastic Processes project-task was, as explained to us in interviews with instructors, designed over several iterations to fine tune and balance the contributions between the different disciples involved. The goal was to ensure that the components to which each group would contribute were roughly similar in terms of the time, energy, degree of intellectual contribution prescribed in the problem; as well as the meaningfulness or relevance of the individual task for each group. In the first iterations of the Stochastic Processes module the project task was not well-balanced – the project could be solved without a solid mathematical contribution. In written feedback in the course evaluation surveys mathematics students reported feeling redundant, and mathematics students evaluated the project lower than the other groups. In 2014/15 for instance mathematics students evaluated the project at 5.3 out of 10 (53% response rate) compared to 6.0 for the other groups (response rates 40%). In response the module coordinators attempted to redesign the project-task to specifically incorporate a mathematical component.

Problem modularization: Lastly a particular feature implemented in the Stochastic Processes task in order to facilite interdisciplinary interaction, is modularity. The project was designed to be decomposable into separate problems which are optimally resolved using methods from specific disciplines. This should not be taken to imply that the problem was simply constructed as separate discrete problems with no interconnections. Rather the required interconnections were not so complex or uncertain so as to prevent disciplines solving their parts effectively. This served to cut down interdisciplinary problem complexity and shift emphasis onto integration. In the Stochastic Processes students are given the following task description:

You are hired by Hans Bakker (a hospital administrator) to provide insight into the following aspects: 1)The effect of the number of resources on the waiting times of patients. This insight should be useable by the hospital management to make a trade-off with the financial implications. 2) The design of an efficient and patient friendly appointment making strategy, where patients are directly informed about their appointment time……. 3) The design of an estimation procedure to provide patients with relevant information regarding their departure time from the hospital. (Case description 2014)

The first bullet point is geared towards the business students and their previous model training in economic analysis, the second and third bullet relate towards both civil engineering and mathematics students. The civil engineering students are meant to cover the traffic modeling aspect, the mathematicians to apply a mathematical approach to estimating hospital waiting and processing times. Students have to integrate their components into a complete working tool. With these integration goals students need to coordinate their activities to ensure their functional components can interact and exchange information on a technical level.

3.2. Risks and Benefits

Based on the data we collected some brief preliminary observations can be made, which might help instructors consider what might be the best options in their case. With respect to deciding whether to pursue an open versus closed design generally, one statistic was reported by students in the Autumn Challenge case, which was not reported in more closed cases (such as in the Science2Society module). Students were asked to compare the depth of project outcomes based on these interdisiplinary open-structured versus what they would produce in a normal disciplinary project. A majority of the Autumn Challenge students (9 of 11; 25%

response rate) reported either lower depth or equivalent depth but less depth than they expected. This points to one issue that project-task structuring is trying to address, namely that open-ended problems can create less opportunity for students to engage in technical work (what we might call the “back-end” of a problem), since much time is invested in formulating a problem and negotiating roles (the “front-end” of a problem). Any form of task structuring, reduces front-end struggles and moves students closer to working on the back end, by scaffolding their initial choices. This is important for interdisciplinary courses seeking to train specific methodological skills.

However the implementation of structure did in our cases introduce trade-offs affecting how modules were perceived by students. Introducing goal or problem structuring risked importing disciplinary biases into the modules. This was not necessarily evident to instructors, as mentioned in the Science2Society case. In this module students formed groups before selecting problems. Some students found themselves in groups in which their skills were not relevant. Structuring can also be explicit. In the Algorithms case, the work required of all students is explicitly computational; mathematics students commented poorly on this fact in surveys, given their role was superfluous and the work could be left entirely to the computer science students. Hence framing tasks structurally risks itself creating biases which then need to be addressed. Open-structured problems may largely avoid such problems, particularly if students are asked to select their own problem. Students in the Autumn Challenge for instance were less likely to see it as important that they were given a fair disciplinary role compared to other roles (14 of 14; 35% response rate). But there are reasons to believe that even largely open problems may nonetheless be unbalanced. When instructors set open problems some formulation or description of the problem and its goals may be necessary to adapt them to the disciplines involved in the programme, or to fit the themes of the course. While it may not be always obvious, problem descriptions can restrict problems in ways which prioritise types of solutions over others, and in turn, types of disciplines over others.

A second issue is artificiality or potential loss of realism. This is perhaps most acute in the case of problem-balancing, in which the goal is in effect to generate an artificially balanced problem. In the real world problems are unlikely to arrive balanced. For instance in the Stochastic Processes course students are asked to build an online appointment tool which takes into account both hospital processing times, but also car parking and travel times. This gives a role to civil engineers, who learn traffic modeling, but is not a realistic request. A hospital administrator is unlikely to be interested in having a system which works so specifically door-to-door for patients. These moves have consequences. Some civil engineering students in written feedback did cite this negatively, consistent with the theory that overly artificial problems can affect student perceptions of educational value and motivation [6], and lessen the chance to acquire skills relevant in particular to grappling with the uncertainty of real world problems.

Finally it can be very hard to design meaningful interdisciplinary project tasks if the instructors themselves have had little experience of integrative interdisciplinary work, and thus have no sense themselves of how to coordinate and integrate methods across disciplinary boundaries. Instructors in the Stochastic Processes module reported the difficulty of constructing a balanced and modularized problem, given primarily a lack of experience working together, but also given the different institutional objectives with respect to the learning objectives each discipline had for their own students. It took several iterations before they were able to find a reasonable balance which was still not perfect at the time of our study.

4 SUMMARY

In this paper we report on an initial investigation of project-task structure in interdisciplinary modules at a Dutch technical university. We find that most structure their problems – despite a prevailing view on the need for open-structure for interdisciplinary education. We outline the types of structuring and examine the motivations for each, and risks, which emerged during our study.

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EXPLORING ENGINEERING STUDENTS' PERCEPTION OF THEIR CAREER PREPAREDNESS IN A SYSTEMIC PBL CONTEXT IN DENMARK

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ABSTRACT

The demand for graduates who are well-prepared for employment remains a persistent concern. This study aims to examine the perceptions of career preparedness among engineering students in a systemic problem-based learning environment, employing a gender perspective. The data for this study was collected through two focus group interviews conducted with engineering students in their eighth semester. The collected data was then coded, resulting in the identification of three main categories: (1) professional competence development, (2) career anticipation, and (3) gender role. The findings of the study reveal that collaboration with external companies and the provision of practical support play a vital role in enhancing career preparedness among engineering students. However, the students demonstrated limited considerations regarding their future career plans. Furthermore, notable differences were observed between male and female students in terms of their perceptions of their acquired technical-profesional skills. Based on the study's outcomes, recommendations are provided for the engineering programme. These

recommendations emphasize the importance of offering adequate support to female students, with a particular focus on recognizing their strengths.

1 INTRODUCTION

From a career development perspective, the period of time spent at university is recognized as a crucial phase, particularly during the final years where students face the transition from school to work. This increases the importance of engaging in proactive career behaviors (Jaensch et al. 2016; Hirschi et al. 2014). The concept of career preparedness has become an increasingly relevant topic that requires intensified attention from both educational practice and research. Specifically, within the field of engineering education, the shift towards Industry 5 has placed significant demand on engineers' general competences, pressuring educational institutions to undertake the challenge of integrating specific competences required by the industry (Isaeva and Grigorash 2023). Within literature examining career preparedness, efforts have been made in a list of research topics including identification of competences associated with career readiness (e.g., Anastasio and Morehouse 2019; Isaeva and Grigorash 2023) and interventions to it (e.g., Hanafit et al. 2022). Despite the increasing attention to career preparedness in higher education practice research, Marciniak et al. (2022) argue that research within career preparedness is fragmented, resulting in a lack of consensus on how to describe different constructs and thus what support students' career preparedness. Therefore, there is a need for further research on career preparedness in engineering education that addresses the complexity of various interactive factors, including employability skills development, intervention strategies, and career exploration. The demand for graduates who are well-prepared for employment is persistent, especially with the changing demographics of countries that generally impose more diversity (Kendricks et al. 2019).

The aim of this study is to investigate the perceptions of career preparedness among engineering students in a systemic Problem-Based Learning (PBL) environment in Denmark, in which students work in semester-long team projects collaboratively solving real-life and complex problems (Holgaard et al. 2021). Moreover, it employs a gender perspective, as previous research has highlighted the important role of gender in students' career pursuits (Ghofur et al., 2020). Particularly, this study was guided by the research question: How do engineering students perceive their career preparedness and the role of gender in their career choices? To address this question, a qualitative study was conducted using focus groups as the primary data source.

1.1 Career preparedness

Despite a multitude of research into career preparedness, there remains a notable shortage of a shared conceptualization surrounding the topic. There has been a tendency to use different labels to describe the same underlying constructs, such as career readiness and career maturity. Lent (2013) describes career preparedness in the context of post-entry employment, characterizing it as a state of vigilance that involves recognizing threats to one's career well-being and identifying opportunities and resources that can be utilized. Similarly, Marciniak et al. (2022) defines career preparedness as a combination of attitudes, knowledge, competences, and behaviors necessary to navigate expected and unexpected career transitions and changes. Readiness is often considered a direct synonym for maturity, as it is included in the definition of maturity as well (Marciniak et al. 2022). Super (1955) was one of the early scholars who introduced the concept of career maturity as a crucial attribute that students must possess to manage developmental tasks at different stages, indicating their readiness for making age-appropriate decisions (Marciniak et al. 2022). Career maturity comprises two distinct stages, namely (1) attitudes towards and (2) competences for developing a career (Super 1955; Super et al. 1996). Prior literature has proposed that female adolescents may engage in career exploration and decision-making earlier than their male counterparts, although this difference tends to diminish with age (Patton and Creed 2002). Conversely, other research advocates that there is a minimal to no difference in terms of career maturity between male and female adolescents (Jawarneh 2016; Ghofur et al. 2020). According to Amelink and Creamer (2010), specifically female engineering students' perception of their academic ability may be adversely affected by an absence of respect and support from their peers.

Lent (2013) suggests that life preparedness should not be equated with career preparedness, as individuals may be well-prepared to enter a particular field of work but may not be adequately equipped to deal with the various obstacles they may encounter. Also highlighted by Lent's (2013) work, preparedness may involve two general types of activities: (1) routine career renewal and (2) preparation to cope with particular events. While the former relates to job-specific activities, the latter is more broadly focused on activities such as maintaining a professional network, exploring job opportunities, and envisioning different scenarios. Preparedness can lead individuals to be more likely to adapt proactive strategies for managing obstacles, building support networks, and advocating for their own career and life aspirations (ibid.). This, in turn, can facilitate the realization of one's potential, particularly in relation to the development of planful competences in career development (Savickas et al. 2002). This perspective serves as a foundational conceptual framework for examining career preparedness in the present study's research design and data analysis.

2 METHODOLOGY

2.1 Context

The study was conducted within the context of a Danish university that has embraced a systemic Problem-Based Learning (PBL) methodology as its primary approach to learning and teaching. Within engineering programmes, students engage in collaborative project groups on a semester basis to address identified problems within their respective domains (Holgaard et al. 2021). To explore students' experiences and opinions, two interviews were conducted with two distinct project groups in the eight semester of a Master's degree programme, although with varying specializations but centred on the theme of sustainability. The first group, henceforth referred to as Group 1, included one female and three male students, whose ages ranged from 23 to 25. The second group, henceforth referred to as Group 2, consisted of three female and one male students, whose ages ranged from 24 to 28. Notably, the students within each project group possessed familiarity with one another, having worked together for a duration of three months prior to the interviews. Within Group 1, all members possessed a Bachelor's degree from the Bachelor Programme. Contrarily, Group 2 comprised two female students who possessed a Bachelor's degree from a foreign institution, one female student who had earned her Bachelor's degree from a different university within the same nation, and one male student who was an international exchange student for this semester.

2.2 Data collection and coding

In qualitative interviews, the emphasis is placed on capturing interviewees' perceptions and perspectives, rather than seeking quantified answers or establishing causal effects (Brinkmann 2022), rendering it as the most suitable approach for the present study. The use of focus group is aimed at generating diverse viewpoints on the topic, rather than arriving at definite solutions to the issue (ibid.). Prior to conducting the interviews, an interview guide was developed, serving as a script that enabled the interviewer to follow up on interviewees' responses, indicating a semi-structured interview approach (Kvale 2007; Brinkmann 2022). The interview guide consisted of seven questions relating to students' actions on career preparedness, challenges and institutional support, future perspectives, and gender role on career development.

The coding process applied in this study followed an open coding, or data-driven, approach, whereby the codes were generated through a qualitative analysis that involved examining the relationships between the codes and their context (Kvale 2007; Gibbs 2007). The process generally involves the identification of passages containing similar ideas and assigning a name, or code, to each idea (Gibbs 2007). Prior to the coding process, the two interviews were transcribed, and subsequently coded independently by the first two authors, followed by a comparison of the coded transcripts. Initially, an inductive approach was employed, wherein themes emerged from the data itself, and subsequently following a deductive approach, wherein the identified themes were organized and categorized into three overarching categories that captured the major findings.

3 RESULTS

In the following subsections, the results from the two focus groups with engineering students are presented. Three major categories were identified from the thematic analysis, highlighting students' emphasized views regarding their career preparedness, namely: (1) Professional competence development in a PBL environment, (2) Career anticipation, and (3) Gender role. Fig. 1 presents an overview of the categories including themes that are reflected within each category.

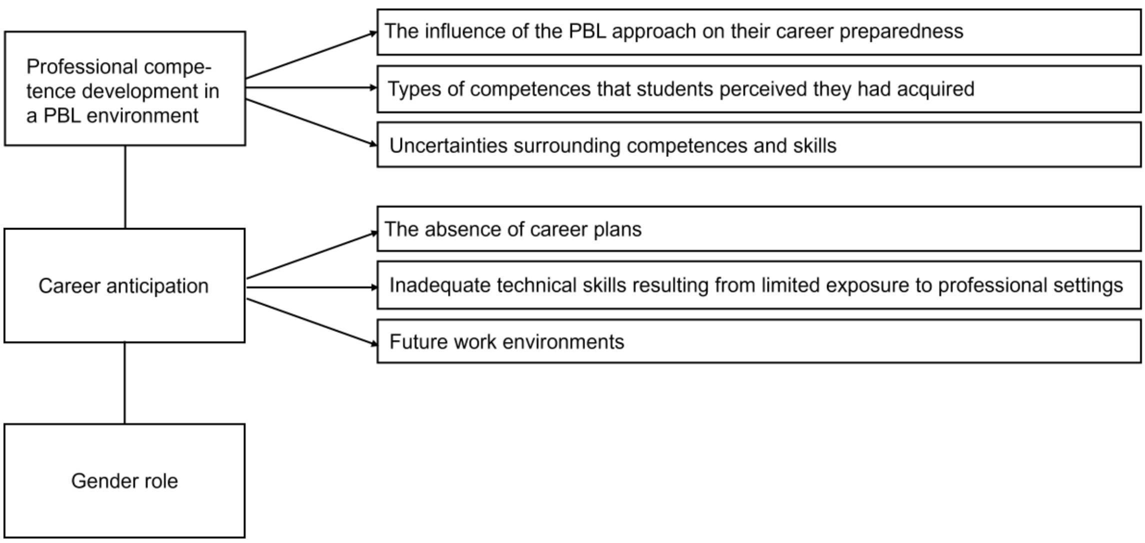

Fig. 1. Categories identified in the thematic analysis

3.1 Professional competence development in a PBL environment

The first category covered three themes associated with: (1) The influence of the PBL approach on their career preparedness, (2) Types of competences that students perceived they had acquired, and (3) Uncertainties surrounding competences and skills.

All students emphasized PBL as supportive for their career preparation, especially with regards to opportunities of having access to professional practice through collaborating with external companies, for example, "*We get used to communicating and collaborating with people in the work-life and gain knowledge on how to do so*" (A1), and additionally, "*It's the PBL mindset. We become adept to identifying and formulating problems, and we don't just receive knowledge from lectures that we don't know how to apply in practice*" (B1). Moreover, all students cited generic competences such as working autonomously, structuring one's own time, communication, learning to work with diverse individuals, and project management. The opportunity to experience how work-life is structured through PBL was similarly highlighted, "*Even though it's stressful, I think that's more like how you work in real life. I have a friend in another university where it's all assessments. I like that you have a project you can go in depth with*" (B2). The students generally emphasized that working with external partners provides valuable insights into the tasks of other employees, thus also increasing their confidence in their own knowledge, "*Right now, we are working with [a company] in [a particular African country], where what we are producing will actually be used. The project won't just be put away afterwards*" (B1).

The majority of the interviewed students expressed a desire for easily accessible opportunities to upgrade their skills and knowledge. Specifically, they expressed a general wish for more elective courses, "*Then you'll also have the opportunity to specialize in different aspects of your field depending on what you need. If someone wants more technical skills, then go do that*" (D1). Following this, it was emphasized that such courses need not necessarily be credit-bearing but could instead take the form of workshops where students can acquire different skills within relevant software, "*Without this scramble for higher marks. Where you just get the opportunity to play with the software*" (A1). Additionally, the potential benefit of obtaining a certificate that could be appended to one's curriculum vitae (CV) was emphasized, "*I can't draw, and the department hosted a graphics workshop for public facilitation, and we got a certificate in the end, something I can actually show*" (C2).

Most of the interviewed students also stressed the need for practical support, such as assistance in choices undertaken during one's education. For example, assistance in choosing their Master's degree, particularly when applying to institutions outside their current one, and support in finding internships during their Master's programme and gaining knowledge about potential career paths after graduation, "*More help for the internship search and more knowledge about where the alumni students went. It would be good to have more connections to the alumnis to get a better network and to find out what could be possible for me after university, like where did the other students go?*" (A2). The need for flexibility in their studies to explore different specialties and find their ideal path was specifically mentioned, "*Especially after Corona, because during Corona, your life was thrown up in the air, and you needed to find yourself in a new way, which I haven't tried before. Back then, during Corona, I felt like the university was more about keeping one's nose in the groove*" (D1).

3.2 Career anticipation

The second category comprised three themes of student perceptions including main concerns of: (1) The absence of career plans, (2) Inadequate technical skills resulting from limited exposure to professional settings, and (3) Future work environments.

All interviewed students reported lacking a clear career plan at this stage of their study. Nevertheless, they expressed different attitudes towards their forthcoming future as engineers. Group 1 students expressed optimistic views regarding their future career, "*I think the future for graduates within our specific education is very optimistic with low rates of unemployment, and those who're unemployed have chosen it themselves. So, it's a very open and optimistic future*" (B1). Conversely, Group 2 students expressed difficulties in predicting the prospects of their future career and highlighted the need for more experience, such as foreign company exposure and internships.

The interviews disclosed a collective apprehension among all students regarding their levels of technical skills; however, female students expressed a greater degree of concern compared to their male counterparts. The male students acknowledged the potential for skill development in the workplace, for example, "*Personally, I'm worried if my profile is technical enough, but that's also something you can develop over time, and it also depends a lot on the company, because they often have a specific way of working, specific software, and so on*" (D1). The male students also emphasized the value of other strengths and attributes that could be offered in place of lacking technical skills, for example, "*Sometimes you feel like you lack some competences, but if you list the ones you have, then you feel like you actually have plenty of competences*" (A1). Among female students, this concern was more pronounced, and the majority of female students expressed an apprehension in relation to their technical skills, "*I don't feel confident in my skills at all*" (A2) and "*I often feel like we are missing specific knowledge and that it's more about the soft skills*" (D2). A similar viewpoint relates to apprehension regarding fulfilling the required technical skills in their field of study. The uncertainties were elaborated upon, "*I'm afraid I won't have the skills that they're looking for. When I tell people I'm studying something in sustainability, they're usually like 'oh, you're probably going to find a job rather quickly', but I'm still unsure if that means a guaranteed job*" (B2).

Notably, the interviewed students underscored the significance of work formats, particularly teamwork within professional settings, placing greater emphasis on this aspect than on physical conditions. Such expressions also demonstrate the students' recognition and appreciation of the PBL environment throughout their studies. For example, "*I like the way we are working in semester projects, so therefore I would like to work in a team*" (A1), followed by highlighting the significant adjustment required to conform to structured work schedules in a professional environment, as opposed to the greater autonomy afforded in project work. Similarly, feeling comfortable was highlighted, "*I'm worried about if I find a position where I'm really comfortable and also like the team and feel like I can thrive there*" (D2).

3.3 Gender role

The third category concerns the viewpoints of both interviewed female and male individuals regarding gender disparities in the labour market, specifically focusing on general and stereotypical inequalities as well as self-efficacy.

All interviewed students demonstrated a comprehensive understanding of gender-related perceptions in the labour market. They expressed concerns regarding gender stereotypes prevalent in engineering workplaces, drawing primarily from knowledge acquired through familial influences, media sources, and their labour union. Notably, the students highlighted wage inequality between male and female employees occupying the same positions, as well as challenges faced by females in resuming their careers after maternity leave, among other related issues.

Personal concerns were particularly expressed by female students. For example, one female student noted her view that the gender differences regarding professional confidence which might be related to the observed inequalities. In her view, male employees could be more self-assured regarding their skill set, "*It can be discussed whether that is because men are better at saying 'here I come' when they get some leading positions*" (B1). Another female student theorized that the notion of females being less confident than males is a widely accepted perspective: "*I think the mainstream thought is that women are not that confident. In previous years it would have been hard for women to have an engineering career, but that should have changed now. But I think women are not that good at selling themselves for their skills*" (A2), indicating that females tend to demonstrate more humility in terms of their skills and knowledge. Moreover, gender stereotypes regarding the types of competences that are attributed to female and male employees appear to exert a considerable influence on contemporary society. Particularly, female students report feeling stigmatized and labelled as possessing primarily 'soft skills', "*In my work life outside of the field of my education, men have been calling me 'sweetheart' and I've got the comment 'oh we don't see a lot of women doing that task'. And I'm like 'okay'*" (B1). Another female student continues, "*This is a hypothesis, but because you are a woman, they might think that you might be better in your soft skills naturally. So, they might give you the positions where you have more communicative roles, and you talk more to people. Again, I haven't tried it, so I don't know if that is reality, but it's my perception of reality*" (B2).

The interviewed male students demonstrated their acknowledgment of prevalent gender stereotypes within professional environments, although expressing varying degrees of disagreement with them. For example, a male student argued that females might feel like they need to choose between having children and a career, "*Maybe it's a bit Hollywoodish, but sometimes you talk about real businesswomen who choose to have children by 40 and focus on their career. You know, that you don't have the possibility to have both, which it maybe sometimes isn't*" (D1). Another male student argued that the gender division within the field of engineering is influenced by societal norms. He further elaborated by stating that they as male students may not be able to accurately assess the frequency of such problems in the field, "*We are three white men, and you need to look at the problem from other angles, and not to choose what problems you think others might have*" (C1). Another male student discussed the idea of potential advantages of being a female in the field of engineering, citing new public reforms that prioritize the inclusion of women in the workplace, "*It is a positive progress that they're searching for more women, but I also don't think it should shift, so that you are chosen based on your gender*" (A1).

4 DISCUSSION AND CONCLUSION

The current study investigated the perceptions of engineering students regarding their career preparedness and the influence and role of gender on these perceptions. The research involved conducting two focus group interviews with engineering students in their eighth semester, and a coding process was employed which identified three distinct categories, namely: (1) Professional competence development in a PBL environment, (2) Career anticipation, and (3) Gender role.

Within the first category, labelled as “Professional competence development in a PBL environment”, the students emphasized the pivotal role of PBL in preparing them for their entrance into the labour market. They underscored the value of acquiring generic competences and actively interacting with stakeholders as integral components of the PBL experience. This observation aligns with the findings of Anastasio and Morehouse (2019), who conducted a study investigating competences associated with career readiness among engineering students. Their study revealed that students exhibited the highest levels of confidence in critical thinking, teamwork, and professionalism, also aligning competences related to PBL. Additionally, the interviewed students expressed the need for enhanced practical support, including guidance in selecting an appropriate Master’s programme, facilitating internship opportunities, and exploring possibilities relevant to their status as students. The second category, labelled as “Career anticipation”, revealed that although the students held varying perspectives regarding the likelihood of securing immediate employment after graduation, a common finding was the absence of a specific career plan among the students. Their limited considerations about a future career plan can indicate a low level of preparedness, as according to Lent (2013). Nevertheless, despite having no clear career plan, the students were still concerned about their future career, but they maintained a desire to further develop their technical skills within their academic pursuits. Furthermore, both groups underscored the significance of acquiring practical experience and working in a beneficial environment. The third category, labelled as “Gender role”, pertains to observations made regarding gender differences and societal positions. Despite the students having a shared understanding of inequalities between genders in various areas in the labour market, gender differences and differing perceptions regarding prospects were evident among male and female students. Specifically, female students expressed apprehensions regarding their technical skillset and perception of females in the labour market, relating to females’ societal position within the job market. The male students generally acknowledged the presence of such, but also emphasized their disagreement with them.

For the purpose of enhancing the career preparedness of engineering students, outcomes of this study provide a few practical implications for future practice. Firstly, the engineering programme should provide more structured support to aid students in developing awareness of their career anticipation and rely on available resources to make a comprehensive career plan. Secondly, the programme needs to emphasize fostering external connections with relevant companies to facilitate practical industry exposure. Particularly, attention can be paid to support female students and others by providing increased opportunities for interaction with industry professionals and graduates who are already employed. Furthermore, it is essential to provide support to students, with particular attention to the needs of female students in recognizing and leveraging their strengths. This support should include the development of both generic competences and technical-professional skills, as creating opportunities and offering comprehensive support and guidance throughout the career development process is vital in addressing these challenges effectively (McDonald and Waite 2014).

The present study has a few limitations. Despite not aiming at statistical representativeness, the results remain temperate due to the explorative nature of focus groups and minor sample size. Future studies may explore career preparedness in a PBL environment by employing diverse research methods, including mixed methods approaches. Furthermore, future studies can explore a larger scope of diversity perspectives, not limited to gender, as it is crucial to gain a deeper understanding of how engineering curricula can be designed to attract a more diverse population. This study seeks to provide valuable student-centered insights that can inform curriculum development efforts, with an emphasis on gender. Currently, the results are limited to the specific engineering programme and further studies are needed to expand the implications of the study.

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A CRITICAL REALIST INVESTIGATION INTO THE DEVELOPMENT OF ENGINEERING ETHICS EDUCATION IN IRELAND

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ABSTRACT

The paper reflects on the use of critical realism as a theoretical lens for examining the provision of ethics in engineering programmes and putting forward recommendations for the development of engineering ethics education. It is based on a large scale 4-year mixed methods study in which 23 engineering programmes from 6 higher education institutions in Ireland participated. The methods used include documentary analysis of programme documents, course syllabus and accreditation reports, interviews with instructors and members of accreditation panels, participant observation at accreditation events and a descriptive statistical analysis of the numerical grade used by engineering programmes to self-assess their provision of ethics. The paper addresses two research questions: 1) what are the key challenges in the provision of engineering ethics education, considering the 23 programmes analysed? 2) what recommendations emerge to address these challenges? To respond to the research questions, given the stratified ontology presupposed by critical

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realism, the research study focused on 4 different levels of analysis: individuals (engineering ethics teachers), institutions (engineering programmes) and policy (national accreditation body). The main insight of the paper is that change strategies need to address all levels and treat them as intertwined in order to develop comprehensively the education for engineering ethics.

1 INTRODUCTION

Traditionally, disciplines such as engineering and exact sciences were regarded as morally neutral [1]. Ethical concerns are a more recent addition to engineering programmes, and the development of engineering ethics education (EEE) has been slow [2]. Moreso, both teachers and programme leaders have reported struggling to make sense of the variety of EEE theories, learning goals, teaching activities, and assessment methods, as to ensure their alignment [3]. There is also a disparity between the perceived importance of societal-related practices by engineering faculty and their actual presence in the engineering curriculum [4].

Accreditation has been mentioned as a factor of change leading towards an enhanced presence of ethics in the engineering curriculum [5]. In Ireland, the accrediting body Engineers Ireland has been actively working on reformulating accreditation criteria aligned with current societal needs and research evidence [6] [7]. The present research study was conducted in collaboration with Engineers Ireland between 2017-2020, with the aim of informing the revision of criteria purporting to societal aspects. When the study was conducted, ethics was already an accreditation outcome, which required that engineering graduates in Ireland show “knowledge and understanding of the social, environmental, ethical, economic, financial, institutional, sustainability and commercial considerations affecting the exercise of their engineering discipline”, as well as “knowledge … of engineering practice, and the impact of engineering solutions in a societal and environmental context” and “commitment to the framework of relevant legal requirements governing engineering activities, including environmental” [7].

The study aims to examine the current status and implementation of EEE in Engineering Programmes in Ireland, and on the basis of the findings to identify change measures for enhancing EEE. 23 engineering programmes from 6 institutions in Ireland took part in the study, alongside 16 instructors teaching in these programmes and 6 evaluators serving on panels accrediting the participant programmes. We argue that change measures need to address several levels pertaining to teaching, programme leadership and policy-making to ensure a transformative engineering education oriented at addressing the grand societal challenges of the time. As such, the study provides insights for lecturers and programme leaders, in response to the need for guidance on how to implement EEE and the increased calls for engineering programmes to take on a societal role.

2 METHODOLOGY

The paper reports on two key research questions: (Q1) How is EEE implemented in Engineering Programmes in Ireland? and (Q2) What are the key recommendations emerging for enhancing the implementation of ethics in Engineering programmes in Ireland?

2.1 Theoretical perspective

When designing the study, an important step was opting for a theoretical paradigm that supports the project aims. As such, we purposefully steer the balance towards describing the theory behind the study. We consider it is important for engineering education researchers to reflect and make explicit how their research is loaded with specific ontological, epistemic and axiological assumptions, which may influence the data collection and analysis. With few exceptions [8], engineering education research is conducted in the absence of such reflections, or these are neglected in the reporting of findings. This carries the risk of acontextual or uncritical research processes, that “limits what can be seen, known and understood.” [9]

To address the research questions set for the project, the theoretical stance adopted by this research study is critical realism (CR). This is due to three main reasons:

First, from an ontological perspective, CR is committed to understanding the embedded nature of human action and the interaction of structure and agency [10] .CR acknowledges the existence of different ontological domains [11]. Bhaskar [12] distinguishes between three domains of existence: “the empirical” (comprised of observable or experienced entities and events), “the actual” (events that take place and which may or may not be experienced) and “the real” (comprised of causal powers that generate both actual events and experiences). According to CR, structures exercise causal power over individual and collective agents, but agents can also affect the structures they are part of [13]. In this sense, reality is considered to be socially constructed and emergent.

In light of this layered ontology, the role of the researcher is then “to use perceptions of empirical events to identify the mechanisms that give rise to those events” [14]. This seemed important given Sterling’s argument for regarding education as a complex system with a number of different layers [15]. The failure to integrate different layers into models for change has been identified as a gap in engineering education research, with different research communities having focused separately on different levels [16]. More so, higher education research has largely neglected the social context which shapes the activities of individuals [17] [18] [19]. A CR research study on engineering education would thus place the individual in the wider context, as “change based on ‘improving’ individuals will usually be a disappointment if not done with an awareness of the context individuals operate in.” [17] This fits with recent calls for developing change strategies that link different levels in order to generate long lasting and organic transformation [20].

Building on this observation, the second reason for opting for CR is axiological in nature, due to its commitment to social change. The axiology of a theoretical framework refers to the values directing research or the research output. CR puts forward an emancipatory axiology [21] [22]. According to Danermark et al. [23], CR research is driven by the belief that the improvement of society is possible. As such, it is considered to offer “exciting prospects in shifting attention to the real problems that we face and their underlying causes.” [21] Thus, the ultimate aim of the emancipatory worldview advocated by CR is to identify how the features examined in the research study may be changed in order to ameliorate harmful effects or to enhance beneficial effects [22]. This implies a “strong focus on ‘what to do’” to improve the situation under investigation [22]. Godfrey [24] agrees that the analysis of engineering education should focus not only on “characteristics of behaviours and practices”, but also on the values, beliefs, and assumptions that underpin “how these came to be,” in order to enable the development of strategies for change.

Thirdly, from an epistemological perspective, CR looks beyond the empirical to posit causal explanations that target the underlying mechanisms for current experiences, beliefs, practices and events [12]. As such, our claim is not that the data is representative of the Irish engineering education system in its entirety, but rather that it provides useful insights into the way ethics is being understood and integrated. This is achieved though retroductive explanations, starting from the examination of phenomena registered in the “empirical” and “actual” ontological domains to pin possible causes pertaining to the “real” domain [25]. The aspiration is towards “theoretical generalisation” [26], which means that the data can provide theoretical insights that, if acted on, may have a profound effect on the development of EEE.

Thus, the ultimate goal of the CR research project is to facilitate change in the practices of EEE. To achieve this, after identifying the main characteristics of EEE belonging to the empirical and actual domains, a generative explanation will be sought placed in the domain of the real, followed by recommendations for change targeting the different ontological layers of the engineering education system.

2.2 Research methods

Four research methods have been employed to determine the implementation of ethics: (a) document analysis of the documentation which was either prepared by the programmes for accreditation or is available online on the website of all 23 participant programmes, together with the analysis of 11 accreditation reports and 83 course descriptors; (b) participant observation at the accreditation events of 11 programmes offered by 3 institutions and (c) interviews with lecturers from the participant programmes teaching a professional formation course and evaluators who served on the accreditation panels observed and (d) a non-systematic literature review for identifying strategies for addressing the challenges and deficiencies revealed via the previous empirical methods. These methods are seen as complementing each other for developing a comprehensive insight into the implementation of ethics education in the participant programmes and putting forward relevant recommendations. The scope of the study was limited to Engineering programmes that underwent accreditation between 2017-2019. Twenty-three programmes offered by 6 institutions are included.

The main strategy behind the mixed method research approach is summarized in Table 1, alongside a description of each research stage. Stage 1 was the initial stage and had the longest temporal unfolding, which encompassed stage 2. Stage two aimed to complement the scarce data available in the accreditation reports analysed in stage 1, to better capture the process of evaluating EEE for the purpose of accreditation. The preliminary results obtained during stage 1 and the experience gathered during stage 2 informed the approach to the interviews conducted in stage 3. Then the three stages informed the literature review search for recommendations and change strategies mentioned in engineering and higher education journals and conference proceedings.

Table 1. Summary of research stages

Stage	Method	Data Source	Data collected
1	Document analysis (qualitative)	23 Programme documents submitted for accreditation 83 Course descriptors and syllabus 11 Accreditation reports	The topics and learning outcomes employed in connection to EEE Content used in EEE Method of implementation of EEE in the programme Weight given to the ethics outcome in the programme, compared with other accreditation outcomes Recommended changes for improving ethics, according to accreditors
2	Participant observation (qualitative)	3 Accreditation events that evaluated 11 programmes	The views on ethics, engineering and engineering education verbally expressed when evaluating evidence The evaluators' judgement and criteria of how the programmes meet the ethics outcome The guidelines received by the accreditation panel from the accreditation body for evaluating ethics The amount of time dedicated to the evaluation of ethics compared with other outcomes
3	Interviews (qualitative)	16 Instructors teaching EEE 6 Evaluators on accreditation panels	Motivation to teach ethics Personal views on the role of ethics in engineering education Perception on how ethics is viewed and implemented in the programme Approaches to EEE in terms of content, teaching and assessment Challenges experienced with EEE (teaching, preparing for accreditation or evaluating ethics) Views on support received or needed in the teaching or evaluation of EEE
4	Literature review	Empirical and theoretical research sources	Measures and strategies for curricular change Measures and strategies for EEE

3. RESULTS

3.1 The status and implementation of EEE in Ireland

Through the triangulation of data, the study identified the following findings within a CR frame: within *the empirical domain*, the beliefs, understanding and attitudes of representatives of teachers, programme leaders and accreditors towards EEE; within *the actual domain*, the teaching practices of instructors and the measures taken by programmes and representatives of the accrediting body; while for *the real domain*, the study hypothesizes the existence of a cultural level, characterised by the prevalent view that engineering is mainly a technical discipline. The findings are summed up in Table 2.

Table 2. A CR analysis of engineering ethics education in Ireland

<table>
<tr><th>Ontological domain
Actor level</th><th>Empirical Domain</th><th>Actual Domain</th><th>Real Domain</th></tr>
<tr><td>Individual level (teachers; evaluators)</td><td>Ethics is perceived to be a lower status academic subject
Perceived lack of motivation to teach ethics
Confusion as to what falls under the scope of ethics</td><td>Challenges experienced in the teaching and assessment of ethics
Challenges in motivating EEE students
Popular use of sustainability, health & safety and legislative topics in EEE</td><td rowspan="3">The prevalence in society of a traditional conception of engineering as a purely technical discipline</td></tr>
<tr><td>Institutional level</td><td>Ethics is perceived as a non-essential learning outcome
Ethics is perceived as a curricular add-on to meet the accreditation requirements
Perceived difficulties in finding room of ethics in a crowded curriculum</td><td>Ethics has the lowest weight in the engineering curriculum of all accreditation outcomes
The implementation of ethics is uneven among different programmes
The implementation of ethics is unsystematic
Few or no staff specialised in EEE</td></tr>
<tr><td>Policy level</td><td>Belief that ethics needs to be part of the engineering curriculum</td><td>Increased presence of ethics following the introduction of an accreditation criterion
Less time spent at accreditation events on evaluating ethics, compared with technical outcomes
Lower threshold for what is considered satisfactory evidence for ethics</td></tr>
</table>

3.2 Recommendations for enhancing EEE

Considering its emancipatory axiology, the CR study set to identify via a non-systematic literature review recommendations for addressing the deficiencies previously identified:

At *individual level*, the actions and example set by individual instructors are powerful means to instil educational change. Effective change in universities is bottom-up, incremental, and often invisible, with faculty and administrators representing "active agents in the curricular change process" [27]. The power of example of committed individuals is crucial in highlighting deficiencies and leading redress strategies. To achieve change, collective action and collaboration are important for fostering the overall reorientation of the programme. It was suggested that this can be accomplished through working groups and faculty learning communities, with open discussions in which instructors are encouraged to think outside their discipline and co-create the course and curricular redesign. Individuals can also enhance their teaching by using educational resources, such as the Online Ethics Center, The Ethics Toolkit or The Surf project.

At *institutional level*, an overall redesign of the programme curriculum is crucial. This can be achieved through staff training, hiring decisions targeting EEE specialists, resource prioritization, incentives internalized in the mission and reward system of the institution, accountability in implementing change. It is also important for programmes to gain an external perspective of their EEE curricular offer and teaching approach through participation in EER conferences and engagement with non-engineers, educational consultants and other institutions.

At *policy level,* it is important to acknowledge that institutional change rooted in the demands set by accrediting bodies risk leading to a culture of compliance rather than of transformative change. The recommendation is a continual update of accreditation requirements in consultations with stakeholders representing different technical and non-technical disciplines, as well as the academic and non-academic environments (major employers, private companies, NGOs, communities affected by engineering developments). It is encouraged that non-mainstream perspectives are brought in the formulation of accreditation requirements, such as humanitarian engineering, engineering for peace, the justice pillar of sustainable development or critical feminism. It is also recommended that accreditation bodies offer additional support to programmes in the implementation and teaching of ethics as well as to members of accreditation panels on evaluating evidence purporting to EEE. Such measures include training sessions, expert advice, the development of pedagogical resources or facilitating stakeholder engagement.

At *cultural level*, it is important to address the dichotomy of the "two cultures", that sees engineering separate from social sciences. This implies recasting the discourse surrounding engineering as a purely technical discipline and renouncing the dichotomy between the so-called "hard" and "soft" skills. The main recommendation is to promote a language that describes engineering as a sociotechnical discipline and the development of sociotechnical skills in engineering education. This may begin with reflecting on how the mission of engineering programmes is formulated to pass on the importance of nontechnical content and the aim of producing sociotechnical engineering graduates. It also includes active efforts reflecting through language the role of societal content and non-technical disciplines and striving to communicate this from programme leaders to the teaching staff, and in turn from technical instructors to students. This is a societal effort that aligns with the recent focus and opposition towards unethical practices or climate denial.

3 CONCLUSION

The study examined the status and implementation of EEE in the Irish engineering education system, via mixed methods comprising documentary analysis of programme documents, interviews with instructors and evaluators, participant observation at accreditation events and a non-systematic literature review. It was driven by a critical realist theoretical framing, which guided us into analysing the findings at different layers of the education system and put forward a causal explanation for these findings. From a methodological perspective, the study contributes to the limited number of investigations in engineering education that adopt critical realism [28]. Considering its emancipatory axiology, the study identified several enablers for enhancing EEE, at the policy, institutional and individual levels. The novelty of this study lies in its attempt to explore the interrelationship of different levels belonging to different ontological domains in the context of a national education system. The findings and recommendations are envisioned to be of interest to teachers, programme leaders and policymakers, as to contribute to enhancing EEE beyond the national context examined in the study.

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SHOULD TEACHING GUIDES BE USED AS INDICATORS OF GENDER DIMENSION IN A UNIVERSITY DEGREE?

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ABSTRACT

In order to achieve a truly equality society, universities are making significant efforts towards gender mainstreaming. One of the main pillars of this approach is the implementation of a gender dimension in teaching. To assess the degree of progress towards this goal, suitable indicators, both qualitative and quantitative, are desirable. Surveys could be used to gather students' perceptions or educators' efforts as indicators, but an underutilised source of information is available in the teaching guides. Teaching guides are understood as those open-access documents where the public can find a subject's description, goals, and contents, among other university-specific features.The aim of the study is to analyse whether the teaching guides can become viable tools to assess the degree of implementation of gender perspective in university teaching.

In the present study, 16 teaching guides and their evolution over a five-week-long gender-in-teaching training program have been analysed using a combination of quantitative and qualitative methodologies. The former is based on participants' and the trainer's perceptions, while the latter is based on the appearance of gender-related terms within the teaching guide.

The results show how the teaching guide can provide evidence of the existence of a gender dimension within a subject, but also highlight the urgent need to train educators on how to include this dimension. Additionally, a systematic quantitative analysis of the teaching guides is proposed to assess the degree of gender dimension within a Bachelor's or Master's degree.

The present study might help academic gender policy design bodies to define strategies towards monitoring and promoting gender dimension in teaching. Furthermore, it provides university educators with indications of how to transform their teaching guides according to a feminist point of view.

1 INTRODUCTION

Gender mainstreaming in Academia means integrating a gender equality perspective at all levels, from governance to students and employees (Swedish Secretariat for Gender Research 2016). Here, the focus is put on gender dimension in teaching. It includes not only considering a gender equality perspective in the contents of the subject and teaching materials, but also the design and implementation of a wide variety of teaching activities regarding, for example, the distribution of the speaking time or the roles within a teamwork. Through teaching with a gender dimension one expects to reduce the gender biases among students, to avoid the stereotyped roles in teamwork, and, as a whole, to generate the proper atmosphere and culture to enable students to develop gender equality skills and to include equity in their future professional careers.

Gender dimension in teaching must affect the four teaching pillars being the contents, the learning environment, the methodology and the assessment. The introduction of a gender dimension in the contents pillar is deeply topic-specific, for example, within a topic of air conditioning and heating in the heat transfer subject of engineering studies, gender biases could be identified in the temperatures of comfort imposed by the corresponding regulation. The learning environment with a gender dimension includes students' management, such as the gender distribution of participation, the roles chosen within a teamwork, etc. The gender dimension can enrich the chosen methodology, especially in those activities where student participation is relevant. Finally, the assessment can also include the gender dimension when considering the needs and preferences of all genders and when evaluating the gender-related activities included in the matter (Mas de les Valls and Peña 2022).

To achieve this goal, universities are offering educators trainings and guides. However, without a strong legal support the change will be minimum and driven only by a minority of educators. In this direction, a preliminary effort by the University Quality Agency in Catalunya (Spain) consists in requiring universities to include gender-specific learning outcomes wherever appropriate (AQU Catalunya 2018). An example of such a learning outcome could be to identify how gender influences the selection and usage of a given technique, or to understand the different needs and preferences according to the gender. This requirement from University Quality Agency in Catalunya (Spain) of introducing gender-specific learning outcomes is applicable for all university degrees, supervised during its accreditation but also at its follow-up (compulsory processes belonging to the quality assurance field). These gender-specific learning outcomes should be written in the public document where the subject is described, together with the goals, the methodology and other university-specific items. This document is hereafter called teaching guide.

As a consequence, a potential strategy to assess the degree of introduction of gender perspective in university teaching can be to analyse the teaching guides. However, the individual reading of such a massive number of documents is unaffordable. Following (Okoye et al. 2020) in their analysis of students' evaluation of teaching, innovative methods need to be developed to accurately extract gender information from the teaching guides and to transform it into actionable insights for decision-making. Such methods might relay in text mining methods, closely related to natural language processing (Pandey and Pandey 2017).

The main goal of the present study is to discuss the usage of the teaching guides as evidences for a systematic methodology to evaluate the degree of gender dimension implementation in a subject. It will be done based on the experience gained in an online 5-week-long gender-in-teaching training carried out at a public university in Spain, in October 2021. In this training, participants (all of them university educators) were asked to successively transform their teaching guides according to the concepts, activities and discussions carried out throughout the sessions.

Two research questions will be assessed: (1) Is the teaching guide representative of the degree of the implementation of the gender dimension in the subject? and (2) Could a systematic methodology be designed to evaluate the degree of gender dimension implementation in a subject through the analysis of the teaching guide?

The present study might help academic gender policy design bodies to define strategies towards monitoring and promoting gender dimension in teaching. Furthermore, it provides university educators with indications of how to transform their teaching guides according to a feminist point of view.

2 METHODOLOGY

The gender-in-teaching training was focused on the transformation of the teaching guides. It consisted of 5 online sessions, spaced one week. Each session was 1.5 hours length and assignments were provided between sessions. There was a digital platform to exchange material such as bibliography, collaborative walls, forums, tasks and individual feedback. At the end of the training, each participant had a revised teaching guide of a their subject. To do so, a general teaching guide template was designed and provided to participants.

Sessions were designed according to the feminist digital pedagogy (Jiménez-Cortés and Aires 2021) using a student-centered approach (Wright 2011). The design of the training is a result of previous experience gained by the authors (Mas de les Valls et al., n.d.).

The total number of training participants was 22, being 86% women and belonging to diverse areas of knowledge, including humanities, social sciences, sciences, ICT (Information and Communications Technology), architecture and engineering. However, current study focuses on the 16 participants that carried out at least 3 of the 5 teaching guide assignments. This subgroup had 87% women and the area of knowledge of its members was also mixed. In fact, 69% belong to a STEM (Science, Technology, Engineering and Mathematics) area. According to the low number of male participants, and in order to preserve the anonymity of the participants, data is not disaggregated by sex or gender.

The degree of gender dimension in the teaching guide is carried out following a similar methodology as in the analysis of the students' evaluation of teaching in (Okoye et al. 2020). This includes the following items to be analysed:

1. The feasibility to introduce gender in the subject's contents. This feasibility is assessed based on the author's experience gained throughout their gender-in-teaching training activities. The subjects' feasibility was classified as High, Medium or Low. A High feasibility is provided to subjects strongly related to persons and their wellbeing such as health sciences, education, communication or even urbanism. However, pure sciences are typically associated with a low feasibility.
2. After a careful read of the teaching guides, the most frequent gender-related terms (GRT) are identified, together with the number of occurrences within the teaching guides in each assignment. An interesting starting point of such list of GRT is the one proposed in (Arias-Rodríguez, Fernández-Sánchez, and Lorenzo-Castiñeiras 2021). To simplify the categories, words' clustering has been used as shown in Table 1.

Table 1: cluster of GRT (gender-related terms) and their assigned weights

CLUSTER	GRT	WEIGHT
GENDER	Gender	3
SEX	Sex, sexual	3
PERSON	Person/s, personal	2
USER	Female user/s	2
EQUALITY	Equality, equalitarian, equity	2
WOMAN	Woman, women, female researcher/s, female scientist/s	2
CITIZENSHIP	Citizenship, female citizen/s	1

3. The coherence throughout the final version of the teaching guide is qualitatively and quantitatively analysed. The qualitative analysis is based on the coherence between the teaching guide contents and the ideas or proposals commented individually with the participants through the training. In this sense, there was one collaborative activity, named Contents Wall, that was of great support. In the Contents Wall, each educator had to define a new teaching activity with gender dimension for his/her subject, with the support, ideas and suggestions of their mates (Mas de les Valls et al., n.d.). This qualitative analysis is supported by quantitative analysis regarding the GRT appearance. The overall result is hereafter identified as the performance of each participant. Accordingly, the overall performance of the transformation achieved by each participant has been classified as High, Incipient, and Stagnant, being classified as Stagnant those cases that either have interrupted the participation in the two latest deliverables or their progress has not evolved significantly.
4. A quantitative estimator of the degree of gender dimension in the teaching guide is obtained from a weighted frequency of occurrence (WFO), being the weight defined according to the explicit relation of the GRT with gender or sex; i.e. a maximum weight of 3 is given to *gender* or *sex* clusters, as shown in Table 1.

3 RESULTS

The evolution of the frecuency of occurrence of gender-related terms (GRT) along the four teaching guide deliverables is shown in Figure 1. The presence of these GRT is only considered when they appear in a context of gender or sex.

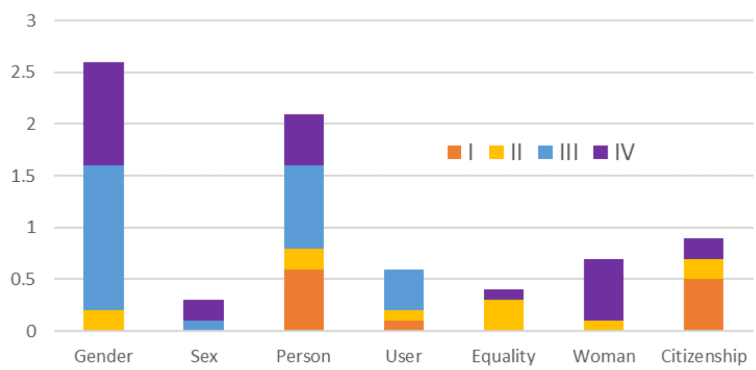

Figure 1: evolution of the GRT frequency of occurrence along different deliverables (I to IV)

A frequency of 0.8 means that, on average, each participant used that GRT 0.8 times in their teaching guide. It is evident that the GRT usage increases throughout the training, with a shift from more general terms (such as *person* and *user*) to more specific ones (such as *gender*).

Despite participants not being aware that this quantitative analysis was going to be conducted, the frequency of occurrence of each GRT might be strongly influenced by the facilitator's inputs throughout the training. For instance, after the first weekly feedback, *gender* and *equality* clusters start to appear. In the last deliverable (IV), female contributions or female case studies were explicitly introduced in the teaching guides, resulting in a significant appearance of the *woman* cluster.

Table 2 provides a summary of both qualitative and quantitative results. For each case, it shows the author's perspective on the feasibility of including a gender perspective in the subject, the initial and final weighted frequencies of occurrence (WFO), and the performance. Additionally, Table 2 indicates whether the participant actively contributed in the collaborative activity called Contents Wall.

Table 2: summary of results for each studied case

ID	FEASIBILITY	ACTIVITY	WFO_I	WFO_F	PERFORMANCE
1	High	Yes	7	41	High
2	Low	Yes	4	--	Stagnant
3	Low	Yes	0	1	Stagnant
4	Low	Yes	1	--	Stagnant
5	Low	No	0	--	Stagnant
6	Medium	Yes	5	49	High
7	High	No	6	12	Incipient
8	High	No	0	6	Incipient
9	Low	Yes	2	10	High
10	Low	Yes	1	3	Incipient
11	Low	Yes	0	2	High
12	Medium	Yes	0	2	Incipient
13	High	No	4	13	Incipient
14	High	Yes	0	0	Stagnant
15	High	Yes	1	58	High
16	Medium	Yes	2	--	Stagnant

As can be seen, participants are distributed quite evenly among the three performance types. Thirty-one percent of the participants show a *High* performance. This does not mean that the results are excellent on their own, but rather that a significant change is observed, and gender has been successfully included in the teaching design. In some cases, the subject easily allows for the introduction of the gender dimension, while in others, gender can only be included through a project focusing on a female referent, for instance.

Furthermore, 31% of the participants are considered to show an *Incipient* performance, indicating that they have defined a gender activity, but the educator has not yet consistently changed the teaching guide or made gender explicit. However, this group of educators has made some changes in their teaching guides concerning the inclusive language and/or the introduction of female authors in the bibliography.

One might assume that subjects with high feasibility would demonstrate better performance and, therefore, be classified as interesting. However, as shown in Table 2, the scenario is different. In fact, 50% of those participants with subjects classified as feasible only achieved a stagnant performance. Generally, participation in the collaborative activity increases the probability of success in the transformation of the teaching guide.

4 DISCUSSION

4.1 Is the teaching guide representative of the degree of the implementation of the gender dimension in the subject?

It is obvious that when gender explicitly appears in a teaching guide within a justified context, the subject includes the gender dimension. However, this does not necessarily mean that the gender dimension is implemented properly or that further development should be done.

Conversely, the opposite scenario is also possible. In some cases, gender does not appear in the teaching guide, but certain gender-related actions are taken during the development of the subject. For example, if female referents are introduced without explanation in the teaching guide, or if the students' learning regarding these gender actions are not evaluated, it represents an incorrect implementation of the gender dimension. Indeed, if it is not evaluated, it is not deemed relevant.

Following the Constructive Alignment theory from its holistical point of view (Loughlin 2021), when educators are aware of what a gender dimension in teaching means, the presence of gender-specific learning outcomes in the teaching guide is a good indicator that the gender dimension is properly implemented. However, among the 16 studied teaching guides, only 3 had learning outcomes that explicitly include a gender dimension. The other participants would require more time and support to further improve their teaching guides.

Therefore, some efforts must be taken before using the teaching guides as a tool to assess the degree of the gender dimension in a subject. Indeed, the majority of educators are still not aware of the meaning of a gender dimension in teaching, and those that are aware and attempt to change their lessons to promote equity are often not yet ready to transform their teaching guides without external support. Once sufficient trainings and continuous support are provided, then teaching guides will be representative of the degree of implementation of the gender dimension in a subject.

4.2 Could a systematic methodology be designed to evaluate the degree of gender dimension implementation in a subject through the analysis of the teaching guide?

Let us assume that within an educational institution, enough gender-in-teaching training and support programs are provided to the teaching staff, making the teaching guide representative of the degree of the gender dimension in a subject. In such a scenario, how could the institution evaluate the degree of gender dimension in a subject? Two potential tools could be used: (1) questionnaires to gather the students' opinions and the educator's intentions, and (2) the teaching guides themselves.

If a comprehensive analysis of the teaching guides needs to be conducted, a systematic methodology must be defined. An interesting approach would be to use the gender-related terms (GRT) and the weighted frequency of occurrence (WFO) as defined in the present study. However, a new question arises: What should be the threshold WFO value to determine that a proper introduction of gender dimension exists?

Considering that the sample size of 16 teaching guides is too small to draw robust conclusions, their analysis can shed some light to the potential of such a systematic tool. Table 3 displays the WFO according to the feasibility of the subject and the performance of the learning/transformational process. A general trend can be observed: a higher WFO implies a better introduction of gender dimension in the teaching guide. However, it is also evident that subjects with low feasibility will never reach significantly high WFO values. Hence, for a systematic analysis of the teaching guide, a preliminary step is required: all subjects must be classified based on their feasibility to include gender dimension. This classification should be conducted by an expert and should motivate gender-unexperienced educators teaching subjects with high feasibility to enroll in a gender-in-teaching training and support programs.

Table 3: final available WFO of each teaching guide classified according to the subject's feasibility

FEAS./PERFORMANCE	HIGHG	INCIPIENT	STAGNANT
HIGH	41, 58	6, 12, 13	0
MEDIUM	49	2	2
LOW	2, 10	3	0, 1, 1, 4

However, this methodology has a potential drawback. Educators may include GRT in their teaching guide without proper contextualisation or without a genuine interest in introducing the gender dimension in their teaching. This risk of transforming an educational tool into an administrative hurdle has been previously highlighted in the revision of the constructive alignment theory (Loughlin 2021).

Additionally, within a team of educators sharing a subject and, therefore, sharing a teaching guide, different levels of gender awareness might exist. Hence, the proposed methodology should also be verified using appropriate students questionnaires.

5 SUMMARY

The transformation of the teaching guides for 16 subjects has been analysed within the framework of a gender-in-teaching training program for university educators in a Spanish university. It has been observed that with proper support, educators can successfully transform their subjects to coherently include the gender dimension. This coherence extends to the transformation of the teaching guides.

Once sustained support is provided to educators, teaching guides can be used in a systematic analysis to quantify the degree of the gender dimension in a given degree program. This comprehensive and systematic analysis could be done based on: (1) a preliminary classification of the subjects according to their feasibility to include the gender dimension, which should be conducted by an experienced gender-in-teaching trainer, (2) the weighted frequency of occurrence of selected gender-related terms, and (3) the students' experiences gathered through a questionnaire.

As a result of this transformation, students could benefit from a more personalised and inclusive learning experience.

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SURVEYING POST-LEAVING CERTIFICATE STUDENTS TO INVESTIGATE THEIR LEVEL OF MATHEMATICAL PREPAREDNESS FOR PROGRESSION TO HIGHER EDUCATION STEM COURSES: A PILOT PROCESS

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ABSTRACT

A student's level of mathematics as they begin degree courses in STEM disciplines has been recognised as a key indicator of their success. While much research has taken place into secondary school mathematics teaching, a comparatively under-researched area has been that of Further Education, which supplies a smaller proportion of degree courses' student intake. The vast majority of Further Education students seeking progression opportunities to such courses study one of three mathematics modules: 'Mathematics 5N1833', 'Maths for IT 5N18396', or 'Maths for STEM 5N0556'.

As part of the author's PhD research project on the mathematical preparedness of students at FE level hoping to progress to a STEM degree course, it is envisaged that a survey of FE students be collected at the end of the 2023/24 academic year as one part of a broader, mixed-methods approach. In the interim, a pilot survey using a convenience sampling method was distributed and collected in April 2023 and is the focus of this paper. 57 responses were collected as part of this pilot process, indicating significant differences between the three module groups.

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1. INTRODUCTION

1.1 Overview

A student's level of mathematics as they begin degree courses at Higher Education (HE) in the Science, Technology, Engineering, and Mathematics (STEM) disciplines has been recognised as a key indicator of their success in those courses. Much research has taken place into the teaching of mathematics at second level, and much work has gone into a reshaped Leaving Certificate (Irish final splecondary school exam) syllabus designed to better equip students to succeed at third level, with greater emphasis on applicable rather than procedural knowledge. A comparatively under-researched area has been Further Education (FE) which supplies a smaller proportion of HE's student intake. The vast majority of FE-to-HE progressions occur from Post Leaving Certificate (PLC) courses, the sector's biggest single course type. Over 842 PLC courses ran in 2018 with approximately 28,000 learners (SOLAS, 2019). This compares to 362,899 students in second level education and 185,474 students in full-time higher education (Education, 2020).

1.2 Progression from the Further Education Sector to Higher Education

PLC graduates have a high progression rate within the HE sector, suggesting high completion rates in years after their graduation from FE (SOLAS & Education, 2020). In the context that PLC learners generally have lower-than-average Leaving Certificate grades, retention figures at HE compare favourably with direct entrants from lower Leaving Certificate points brackets (McGuinness et al., 2018).

Given the focus of this research on STEM disciplines, it was decided to investigate the 2023 entry routes to HEIs in the areas of Science, Technology, Engineering, and Mathematics, with a particular focus on mathematics requirements. An analysis was carried out of the requirements for entry onto what can broadly be defined as a STEM degree course, showing that three mathematics modules are studied at FE for the purposes of progression to STEM degrees, namely 'Mathematics 5N1833', 'Maths for Information Technology 5N18396', and 'Maths for STEM 5N0556'.

1.3 Mathematics in the Further Education Sector

Students studying any of the three FE mathematics modules are expected to achieve proficiency in units similar to those taught in the secondary school system (i.e., number, algebra, functions, calculus, geometry, trigonometry, statistics, and probability). 'Maths for STEM 5N0556' was the last of these modules to be developed, with the context for its development mirroring that of similar changes to mathematics curriculums both nationally and internationally.

The introduction of the Project Maths curriculum on a phased basis since 2010 has brought about significant change in how mathematics is taught and assessed in the Irish second level school system (Prendergast et al., 2017). This has sought to change the focus more towards problem-solving skills and conceptual understanding than a purely procedural approach. A similar problem was also recognised in an FE context, where the existing modules were not deemed adequate for entry to STEM degree courses by universities. A collaborative process involving subject experts (from TU Dublin, TCD, and UCD among others) and various other administrative bodies saw the development of ‘Maths for STEM 5N0556’, a one-year PLC mathematics module designed to be accepted by HEIs as an alternative to the HC3/H4 grade in Leaving Certificate mathematics (Robinson et al., 2018). This module differed significantly from previously existing mathematics modules, as outlined in Table 1 (Curriculum Development Unit, 2018a, 2018b, 2018c).

Table 1: The differences between QQI Level 5 Maths modules, as per module descriptors published by the City of Dublin Education and Training Board (CDETB) (Curriculum Development Unit, 2018a, 2018b, 2018c)

Module Title	Maths for STEM	Mathematics	Maths for IT
Module Code	5N0556	5N1833	5N18396
Level 5 Major award credit value	30	15	15
Directed learning hours (for a standard term of 26 weeks)	150 (typically 6 per week)	75* (typically 3 per week)	75* (typically 3 per week)
Recommended self-directed (i.e. learner-led) hours	150	75*	75*
Qualification requirements for teachers	Degree with strong maths emphasis	No requirements stated	No requirements stated
Number of assessments	5	3	3
Percentage of final grade from proctored assessment	85 – 100%†	40%	40%
Number of specific learning outcomes (SLOs)	97	36	55

**Duration in hours specified by module descriptors as 150 to include both directed & self-directed learning.*
†Option of a 15% Statistics research project which, if not taken, must be replaced by proctored assessment. Also, mastery in the topics of Arithmetic and Algebra must be demonstrated with a mark of >80% in first proctored assessment.

1.4 A Pilot Survey

The author’s PhD research project on the mathematical preparedness of FE students for HE STEM degrees currently involves a plan for data collection by way of a survey of such students nationwide. However, given that this data collection would need to take place towards the end of any academic year, it was felt that there was insufficient time for the planning and execution of a process of this scale in the 2022/23 academic year. It was decided that this would take place in 2023/24 and, in the interim, a pilot survey on a smaller scale could be designed, collected, and analysed with a view to informing this larger process. This would utilise a convenience sampling technique made possible by the author’s own professional background and contact network as an FE teacher in Coláiste Dhúlaigh CFE.

2 METHODOLOGY

2.1 ‘Maths for STEM 5N0556’ Informing a Diagnostic Test of Key Skills

Including a diagnostic test of key mathematical skills in the pilot survey would allow for a comparative analysis of mathematical preparedness of the three cohorts under consideration. Tests of this sort have become a popular tool for measuring mathematical skills (Michael Carr et al., 2013; Carr et al., 2015; M. Carr et al., 2013; Faulkner et al., 2021; Lawson, 1997; Malcolm & McCoy, 2007) and have proven useful for profiling particular cohorts. If such a test were established at this point of the research, further comparison would then also be possible at a later point between these cohorts and the other intake streams for STEM degrees, the largest of which is school-leavers. This would help to give a sense of how FE students compare with others in terms of key mathematical skills upon entry to HE.

It was deemed important that any diagnostic test contained within the pilot survey would have an explicit relationship with the mathematical requirements of STEM degrees in HE in order to align with the central aim of the research, namely to measure the mathematical preparedness of FE students for such a progression. To that end (bearing in mind that the module was devised by subject experts for this specific purpose - see Section 1.3) questions on the diagnostic test were to be chosen using ‘Maths for STEM 5N0556’ as a guide. Its overall aim is described as “addressing the need for adequate mathematical preparation and attainment for FET award holders who wish to progress to STEM degree programmes” and the five components of mathematical proficiency it sets out to develop are conceptual understanding, strategic competence, procedural fluency, adaptive reasoning, and productive disposition (Curriculum Development Unit, 2018a).

The module’s indicative content sets out learning outcomes requiring specific skills to be mastered. While certain of these outcomes do require development of non-procedural skills (e.g., “*Explain the relationship between logical equivalences and set identities*”, “*Investigate the concept of the limit of a function*”, “*Engage in discussions about the purpose of probability*”) they for the most part require the development of procedural fluency skills. Given the constraint on the scope of the proposed diagnostic test imposed by a one-hour time limit (a standard FE class duration), it was decided to structure the initial skeleton of the test around procedural skills. Due consideration would then be given to ensure that all components for the development of mathematical proficiency listed above were also incorporated. Given the role ‘Maths for STEM 5N0556’ was taking in the construction of the diagnostic test, great care would also need be taken to ensure that respondents studying ‘Mathematics 5N1833’ and ‘Maths for IT 5N18396’ would not be at a disadvantage.

Three techniques for administering diagnostic tests are commonly used: computer-based tests, paper-based tests which are optically marked based on multiple-choice answer types, and paper-based tests which are marked by hand (Appleby et al., 1997). The benefits and limitations of each of these choices were considered and the decision was made to use a hand-marked, paper-based test, particularly in light of sample size issues foreseen in the pilot survey and the research more broadly.

2.2 Testing ‘Procedural Fluency’ Skills in the Diagnostic Test

Five units of the ‘Maths for STEM 5N0556’ module populated the ‘Procedural Fluency’ aspect of the diagnostic test. In order to ensure students would be able complete the test during a standard hourlong class, consideration was given to the number of questions which should be asked in this part of the test, bearing in mind that further material testing conceptual understanding, strategic competence, adaptive reasoning, and productive disposition would also have to be included at a later point. A diagnostic test conducted by Faulkner et al. (2021) on entrants to TU Dublin degrees contained 18 questions – 9 testing procedural skills and 9 testing problem-solving skills. This test was completed in 50-minute time slots. Considering this diagnostic test was to be aimed at a group of a broadly similar academic profile (i.e., FE and school-leavers upon completion of their studies vs new entrants to HE) and taking into account the requirement for supplemental questions beyond this stage, a skeleton of ten procedural fluency questions was deemed suitable, allowing for a simple overarching structure of two questions per unit as shown in Table 2.

Table 2: Distribution of Diagnostic Test Questions Across 'Maths for STEM 5N0556' Units

Unit	Number	Algebra	Functions & Calculus	Geometry & Trigonometry	Statistics & Probability
Question Number	1, 2	3, 4	5, 6	7, 8	9, 10

As stated in Section 2.1, respondents studying ‘Mathematics 5N1833’ and ‘Maths for IT 5N18396’ should not be at a disadvantage when completing the diagnostic test, given the role that the ‘Maths for STEM 5N0556’ module played in its construction. To that end, a detailed comparative analysis of the three modules’ indicative content would determine which specific skills to assess in the diagnostic test, such that it could be reasonably expected that all test items could be answered by a respondent studying any of the three modules. This comparison was to be carried out using thematic analysis, a technique outlined by Braun & Clarke (2006) which has been widely used in psychology but can and has also be used in a variety of fields that involve the analysis of qualitative data, including science education (Lemke, 1990). Thematic analysis involves the identification of patterns across datasets and is a technique in which the author’s own subjective experience is centrally important in interpreting meaning from data. Some examples of test items from the pilot survey following this process are shown in Table 3.

Table 3: Examples of Procedural Diagnostic Test Items

No.	**Question**	**Unit**
2	*Simplify $\log_{10}15+\log_{10}4-\log_{10}3$ to a single logarithmic term using the laws of logarithms.*	Number
7	*What is the equation of the line passing through the point (4,3) which is perpendicular to the line $y=2x+1$?*	Geometry & Trigonometry
10	*Two fair dice are rolled. What is the probability of getting two sixes?*	Statistics & Probability

2.3 Measuring the Productive Disposition of Respondents

Stage & Kloosterman (1992) developed an instrument called the Indiana Mathematical Belief (IMB) scales to interrogate students’ beliefs around mathematics and problem-solving. This instrument takes the form of a Likert scale questionnaire investigating five commonly held beliefs about mathematics, namely:

1. *I can solve time-consuming mathematics problems*
2. *There are word problems that cannot be solved with simple, step-by-step procedures*
3. *Understanding concepts is important in mathematics*
4. *Word problems are important in mathematics*
5. *Effort can increase mathematical ability*

These beliefs were chosen by Stage & Kloosterman “because they should help to explain motivation to learn to solve mathematical problems”, and because positive attitudes in these five areas were deemed key to the development of a student’s problem-solving skills. It was decided to include the instrument in the pilot survey as a measure of respondents’ productive disposition.

2.4 The Remaining 'Mathematics Proficiency' Components

The remaining components of mathematical proficiency to be tested were conceptual understanding, strategic competence, and adaptive reasoning (Curriculum Development Unit, 2018a). In order to integrate these components and reflect their importance, it was decided that the existing skeleton of the diagnostic test of mathematical skills would be expanded in scope using supplemental questions.

A summary of where these components have been tested is shown in Table 4.

Table 4: Summary of the Components of 'Mathematics Proficiency' Tested

'Mathematics Proficiency' Component	1: Number		2: Algebra		3: Functions & Calculus		4: Geometry & Trigonometry		5: Statistics & Probability	
	Q1a	Q2a	Q3a	Q4a	Q5a	Q6a	Q7a	Q8a	Q9a	Q10a
'Conceptual Understanding'		✓				✓			✓	
'Strategic Competence'	✓			✓			✓			
'Adaptive Reasoning'			✓		✓			✓		✓

Examples of test items for each of the three components are shown in Table 5, showing also the relationship to the procedural questions in Section 2.2.

Table 5: Examples of Non-Procedural Diagnostic Test Items

Component	No.	Question	Unit
Conceptual Understanding	2a	*Explain your understanding of a logarithmic term such as $log_{10}1000$*	Number
Strategic Competence	7a	*Justify your answer for the above question by plotting both lines on the coordinate plane below.*	Geometry & Trigonometry
Adaptive Reasoning	10a	*When using probabilities how confident should we be in any prediction made? For example, if the probability of flipping a coin and getting heads is ½, should we reasonably expect five heads results from ten coin-flips? What about 1,000 coin-flips? Discuss.*	Statistics & Probability

3 RESULTS

The classes surveyed using a convenience sampling method were studying at Coláiste Dhúlaigh CFE. Of the 57 responses, 16 were studying 'Mathematics 5N1833' (*Pre-University Science* and *Engineering Technology*), 26 were studying 'Maths for IT 5N183962' (*Computer Science 1A* and *1B* and *Computer Networking*) and 15 were studying 'Maths for STEM 5N0556' (*Preliminary Engineering*).

3.1 Diagnostic Test of Key Mathematical Skills

A one-way analysis of variance (ANOVA) was carried out to gauge whether differences existed in diagnostic test marks between the module groups. This and further analyses of sections investigating procedural fluency, strategic competence, conceptual understanding, and adaptive reasoning can be seen in Table 6.

Table 6: ANOVA Results for Diagnostic Test Marks Across the Three Module Groups.

Diagnostic Test Mark	Module	Mean	S.D.	F-value	P-value
Overall (/200)	Mathematics 5N1833	47.19	33.09	19.33	0.000
	Maths for IT 5N18396	49.42	31.32		
	Maths for STEM 5N0556	112.4	39.7		
Procedural Questions (/100)	Mathematics 5N1833	31.81	21.32	11.5	0.000
	Maths for IT 5N18396	32.77	21.15		
	Maths for STEM 5N0556	62.53	19.97		
Questions Testing Conceptual Understanding (/30)	Mathematics 5N1833	3.63	5.66	10.1	0.000
	Maths for IT 5N18396	5.19	6.27		
	Maths for STEM 5N0556	13.47	8.15		
Questions Testing Strategic Competence (/30)	Mathematics 5N1833	8.13	5.95	20.35	0.000
	Maths for IT 5N18396	7.69	6.7		
	Maths for STEM 5N0556	20.67	7.35		
Questions Testing Adaptive Reasoning (/40)	Mathematics 5N1833	3.63	4.9	16.73	0.000
	Maths for IT 5N18396	3.769	4.852		
	Maths for STEM 5N0556	15.73	10.79		

Statistically significant differences between groups were noted across the board in this analysis ($P < 0.0005$), with mean results for respondents studying 'Maths for STEM 5N0556' higher in each section than those studying both other modules.

3.2 Productive Disposition – 'Belief' Scales

In order to determine whether the instrument first introduced by Stage and Kloosterman (1992) could be used to measure respondents' productive disposition, reliability analyses for each of the five belief scales were carried out.

Table 7: Reliability Analysis of the five 'Belief' Scales

Scale	n	Mean	S.D.	Cronbach's α
1: Difficult Problems	57	21.105	4.300	0.7952
2: Steps	55	16.891	3.332	0.5613
3: Understanding	57	24.386	3.569	0.7585
4: Word Problems	55	17.455	3.387	0.4881
5: Effort	57	25.456	3.616	0.8076

The reliability coefficients align broadly with Stage and Kloosterman (1992) and subsequent studies (Mason, 2003; Prendergast et al., 2018) in that Scale 4 cannot be considered reliable with a Cronbach's Alpha measure of 0.49. Thus, the responses from this scale were not considered from this point.

With a Cronbach's Alpha measure of 0.56, Scale 2 should be considered only moderately reliable. Thus, caution will be applied when interpreting respondents' scores in this scale. The other three belief scales can be considered highly reliable, with Cronbach's Alpha measures of over 0.75.

To gauge whether differences existed in beliefs related to the three mathematics modules studied within the sample, a one-way analysis of variance (ANOVA) was carried out using the three modules studied as subject variables and marks in the four relevant belief scales as dependent variables.

Table 8: ANOVA Results for the four 'Belief' Scales Across the Three Module Groups

Scale	Module	Mean	S.D.	F-value	P-value
1: Difficult Problems	Mathematics 5N1833	20.125	2.849	3.77	0.029
	Maths for IT 5N18396	20.269	4.378		
	Maths for STEM 5N0556	23.6	4.69		
2: Steps	Mathematics 5N1833	17.813	3.146	3.26	0.046
	Maths for IT 5N18396	15.654	2.87		
	Maths for STEM 5N0556	17.867	3.833		
3: Understanding	Mathematics 5N1833	23.63	4.06	3.28	0.045
	Maths for IT 5N18396	23.731	3.341		
	Maths for STEM 5N0556	26.333	2.795		
5: Effort	Mathematics 5N1833	25.38	4.88	0.3	0.741
	Maths for IT 5N18396	25.154	2.588		
	Maths for STEM 5N0556	26.067	3.77		

Statistically significant differences in belief were found to exist for Scales 1 and 3 ($P < 0.05$). For Scale 1, respondents studying 'Maths for STEM 5N0556' returned a mean mark of 23.6, whereas those studying 'Mathematics 5N1833' and 'Maths for IT 5N18396' returned lower mean marks (20.1 and 20.3 respectively). Likewise, for Scale 3, respondents studying 'Maths for STEM 5N0556' returned a mean mark of 26.3, whereas those studying 'Mathematics 5N1833' and 'Maths for IT 5N18396' again returned lower mean marks (23.6 and 23.7 respectively).

There were also found to be statistically significant differences between the three module sub-groups ($P = 0.046$) in the Scale 2 responses. Here, the mean marks for 'Mathematics 5N1833' and 'Maths for STEM 5N0556' (17.8 and 17.9 respectively) were both higher than that of 'Maths for IT 5N18396' (15.7). There was no significant difference found between the mean values for the 'Maths for STEM 5N0556' and 'Mathematics 5N1833' sub-groups ($P = 0.966$). However, as mentioned earlier in this section, with a Cronbach's Alpha measure of internal consistency of only 0.56 for this scale, caution should be applied and it may be unwise to infer too much from this result. The results for Scale 5 indicated that while 'Maths for STEM 5N0556' sub-group had a higher average than the others, this was not a significant difference.

3.3 Correlation Between Diagnostic Test Performance and 'Beliefs'

Scatterplots were generated to attempt to ascertain whether a relationship existed between 'beliefs' around mathematics and achievement, as shown in Figure 1 below.

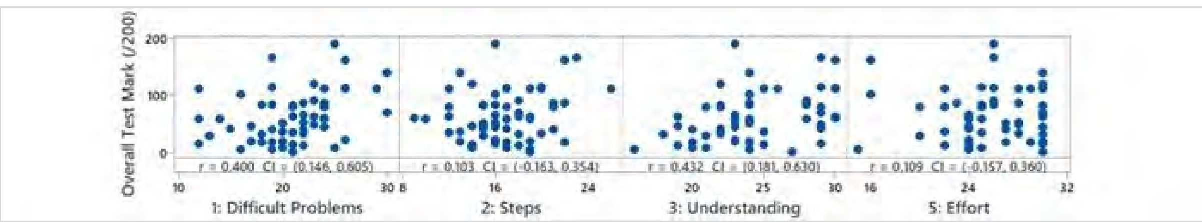

Figure 1: Correlation Plots of Overall Test Mark and the four 'Belief' Scales

Spearman correlation coefficients suggest moderate-to-strong positive correlations between both Scales 1 and 3 and the respondents' performance in the diagnostic test ($P < 0.005$, see Table 9). There was found to be negligible correlation between both Scales 2 and 5 and diagnostic test performance.

Table 9: Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
1: Difficult Problems	Overall Test Mark (/200)	57	0.400	(0.146, 0.605)	0.002
2: Steps	Overall Test Mark (/200)	57	0.103	(-0.163, 0.354)	0.448
3: Understanding	Overall Test Mark (/200)	57	0.432	(0.181, 0.630)	0.001
5: Effort	Overall Test Mark (/200)	57	0.109	(-0.157, 0.360)	0.422

A stepwise regression analysis was also carried out to select independent variables (in the form of 'Belief' Scales) which best predicted the response variable (diagnostic test performance). The order of entry to the model was determined by the Belief Scale which accounted for the most variance at each step, as shown in Table 10.

Table 10: Stepwise Selection of Terms (α to enter = 0.15, α to remove = 0.15)

	----Step 1----		-----Step 2----	
	Coef	**P-value**	**Coef**	**P-value**
Constant	-56.7		-101.6	
3: Understanding	5.00	0.002	4.24	0.006
1: Difficult Problems			3.01	0.018
S		40.4911		38.7744
R-sq		16.54%		24.86%
R-sq(adj)		15.02%		22.08%

Thus, the model determined that Scales 1 & 3 predicted test performance ($P < 0.05$).

3.4 Conclusions

The aim of the pilot survey, as discussed in Section 1.4, was to inform a larger data collection strategy for 2023/24. The results attained give an encouraging indication of how FE students' mathematical preparedness for progression to HE may be better understood. The differences between module groups in contact hours, learning outcomes, and assessments, as well as proctored assessments and teacher qualification requirements (see Table 1) appear to be reflected by significant differences across all of the five components of 'mathematics proficiency' deemed important for FE-to-HE progression. This could also have important implications for progression pathways in other countries with similarly structured education systems.

Any analysis of these results should be qualified by acknowledging the limitations of small sample size and strategy. It is reasonable to think that more reliable results and analysis would be achievable by surveying a broader, national cross-section of FE students in 2023/24. It is also envisaged that the structure and content of the diagnostic test be reconsidered by a subject expert panel from the HE and FE sectors in light of the results of this pilot process to bolster its validity.

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PROBLEMATISING AND FRAMING SPATIAL RESEARCH IN ENGINEERING EDUCATION

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Conference Key Areas: *Engineering Skills and Competences, Lifelong Learning for a more sustainable world*
Keywords: *Cognitive Abilities & Skills, Spatial Terms, Spatial Education Research*

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ABSTRACT

Spatial research has experienced a surge in popularity across the global community in recent years, with an undeniable rise in the favourability of spatial thinking approaches in academic and higher education settings. An engineer's spatial ability is dependent on their capacity to engage a set of cognitive skills to visualise, reason and communicate spatial relations between objects and space. With the recent growth in popularity around spatial research, new spatial terms are frequently introduced resulting in a definitional overlap between terms and ideas. This may sometimes result in a lack of clarity regarding spatial terms and definitions, with the definitions of such terms varying amongst the literature. The eight most researched spatial terms over the last ten years are included in this study: *Spatial Ability, Spatial Skills, Spatial Intelligence, Spatial Visualisation, Spatial Literacy, Spatial Reasoning, Spatial Factors and Spatial Thinking.* A review of literature supported the unpacking of spatial terms and related research and the subsequent synthesis of the same. Particular focus centred on the various definitions and conceptualizations of these terms, as well as the contexts in which they are used to improve the accuracy, validity, and value of spatial analysis and its potential applications across different fields and disciplines. This paper aims to unpack and synthesise the various interpretations and dimensions of spatial competencies in the body of international research, ensuring that the pertinent research information is more readily accessible to practicing engineering educators.

1 INTRODUCTION

Spatial competency skills are widely regarded as a fundamental component of cognitive development, with primary links to problem solving and working memory (Ishikawa and Newcombe 2021). Working memory is a limited-capacity system that stores and manipulates information temporarily for complex tasks such as comprehension, learning and reasoning (St Clair-Thompson et al. 2010). One of the system's key components is the visuospatial sketchpad, which allows people to mentally represent and manipulate visual and spatial information such as mental images, maps, and spatial relationships between objects. It additionally facilitates mental rotation and recall of visual details such as colours and shapes. The ability to hold and interact with visuospatial representations has been identified as a nonverbal intelligence indicator of success in professions such as engineering and architecture (Baddeley 2003). This is supported with the research conducted in recent years highlighting that there is a direct correlation between one's academic achievement, retention rates and spatial ability (Sorby et al. 2018). Coupled with the fact of spatial skills being malleable (Lane and Sorby 2022) and the disappointing fact that students worldwide are entering third-level education with underdeveloped spatial skills (Uttal et al. 2013), it is imperative that we allow our educational systems to be more efficient and sustainable, so to allow every student equal opportunities to develop these spatial skills.

This paper aims to analyse the literature base relating to spatial competencies in Engineering Education, to develop a framework around the use, implementation and definitions of various spatial terms as used throughout the literature between 2012 and 2022 inclusive.

2 METHODOLOGY

2.1 Approach

To clarify the area for new and experienced researchers the most prevalent terminology in the field of spatial research is examined and identifies how each term is used in context to determine a universal definition for each. A three-step approach was implemented in this review:

1. Determine the scope of spatial research over the last ten years in engineering education.
2. Identify the most frequently employed spatial terminology used by researchers.
3. Emphasise links and unique differences between terms, thus determining a universal definition for each.

2.2 Dataset

A series of searches were conducted on the Web of Science, to determine the data selection for this study as shown graphically in *Figure 1*. The 'advanced search tool' was used to identify studies for review while inclusion and exclusion criteria were carefully considered to ensure that the workload was manageable and that a large enough scope was provided to identify trends in the research. As a result, the search was refined to include only articles or review articles. Furthermore, only studies in the field of engineering were considered to narrow the search to ensure that the resulting papers were also sufficiently representative. On February 9, 2022, the first electronic search of this study was conducted on the Web of Science database details of which are highlighted in *Figure 1.*

2.3 Screening

Of the 83,941 papers, the top fifty cited papers were selected and screened by both title and abstract for the next stage of the review. Each paper was examined thoroughly and for every spatial term mentioned an analysis was conducted on how it was used in the paper and the paper's context. For example, both David Uttal and Nora Newcombe believe that spatial skills are distinct from other sets of skills and that depending on the scale of the task, different cognitive processes are engaged (Uttal et al. 2013; Newcombe et al. 2013). From the outlined review (*Figure 1*), eight key terms were identified; *Spatial Ability, Spatial Factors, Spatial Intelligence, Spatial Literacy, Spatial Reasoning, Spatial Skills, Spatial Thinking, and Spatial Visualisation.* An independent search for each key term ("code") was conducted through the Web of Science database under the same conditions as the first search. The following are the results of papers including the relevant term in their writing; *Spatial Ability* (n=171), *Spatial Thinking* (n=59), *Spatial Skills* (n=106*), Spatial*

Intelligence (n=28), *Spatial Literacy* (n=4[†]), *Spatial Visualisation*[‡] (n=93), *Spatial Reasoning* (n=85) and *Spatial Factors* (n=75).

All articles from the search (n= 433) were downloaded into the Zotero reference management software where duplicate articles were removed (n=356) and papers were organised by term into sub folders. For the final phase of screening, the top 20[§] cited papers from each code were included in the review (n=152).

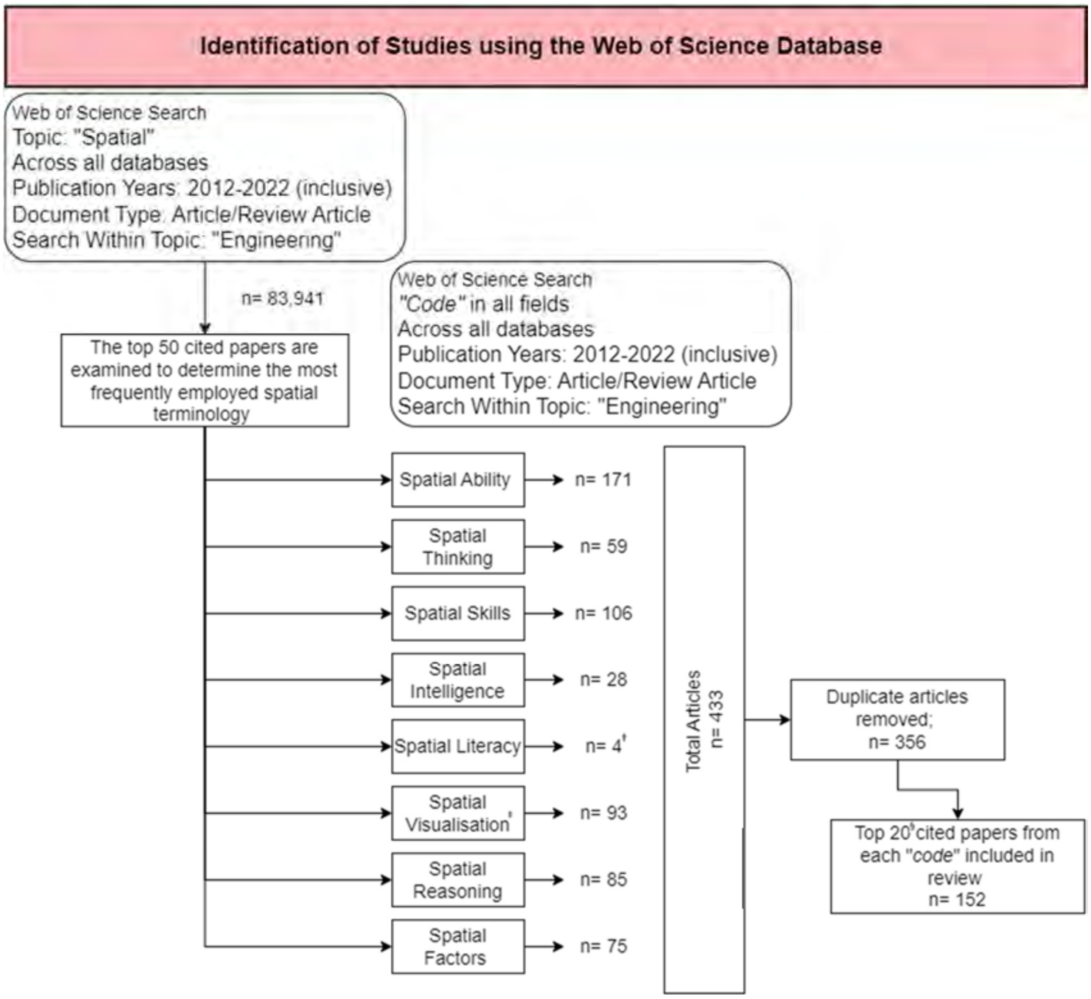

Figure 1. Flow Diagram illustrating the procedure for identifying the spatial terms that occur most frequently in Engineering Education research.

3 RESULTS

The results of this study are summarised in *Figure 3* which highlights the definitions of terms and the key similarities and differences between the areas of spatial research in engineering education. With the consistent increase in peer-review

[†] *In the case of Spatial Literacy all papers were included.*

[‡] *For "Spatial Visualisation", "Spatial Visualization", was also included in the search.*

[§] *For terms >30 results, all papers were included.*

publications in spatial research in the last decade it is paramount that all researchers are well versed in the varying areas and the related terms. This flowchart serves as a comprehensive tool which can be used by both experienced and new researchers mapping a sustainable approach towards an area of spatial research.

3.1 Spatial Ability & Spatial Factors

(Carroll 1993) highlighted that 'spatial ability' is found to be a term of common usage in both academic and everyday conversation, yet its precise definition is seldom considered or clarified. Researchers have the same basic conception of the term with it being described as 'one's ability to comprehend and mentally manipulate objects, shapes, and space in order to navigate and interact with the physical world and solve problems' (Uttal et al. 2013; Buckley et. al 2018; Ganley et. al 2014) However for a true definition, its context must first be considered. Language used in relation to spatial ability attainment is important to note with research most often conducted in relation to the enhancement of one's ability after exposure to spatial interventions. For example, if you were to measure a participants 'spatial ability' before exposure, you would call this measurement their 'innate spatial aptitude' in comparison to after exposure, their 'learned spatial ability' (Buckley et al. 2018). Consequently, it is evident that to define spatial ability you must first explore the factors of which are relevant to its context. Factor analysis is known to be one of the most common methods used to describe the underlying structure of intellect and is specifically implemented through 'paper and pencil tests' allowing for exploration of relationships between variables and the development of a greater understanding of complex data sets (Hegarty et al. 2005)

The Cattell-Horn-Carroll (CHC) theory is widely regarded as being the primary framework of human intelligence and cognitive factors, which in turn aids in defining spatial ability based on its factor structure, as shown in *Figure 2* (Schneider and McGrew 2012).

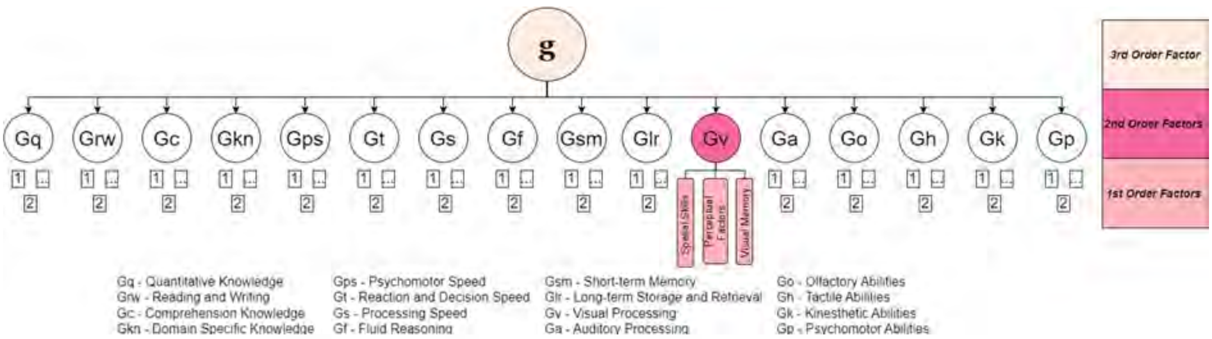

Figure 2. Cattell-Horn-Carroll Theory adapted from (Buckley et. al 2018)

Figure 2 illustrates this hierarchical theory which contains three different orders of factors. The third-order factor (g) at the top of the hierarchy represents one's general intelligence (Spearman 1904) which then filters into sixteen second-order factors representing primary mental abilities. Spatial ability is expressed as one of these second-order factors and is referred to as *Gv*, visual processing. Eleven first-order factors load directly onto *Gv* which are broadly grouped into three categories: spatial skills, visual memory, and perceptual factors. These first-order factors are more commonly known as spatial factors to aid in differentiation between other first-order factors in the theory and are primarily concerned with the various environmental and cognitive factors that contribute to the development and enhancement of spatial skills. Spatial factors are also independent of semantic knowledge as we can understand and manipulate objects in space without relying on previous knowledge or information. Uttal *et al*. (2013) recognises these spatial factors as being related to spatial skills, thus solidifying its definition as a person's ability to mentally manipulate objects and visualise spatial relationships such as distance and size. There are both dynamic factors, relating to movement, and static spatial factors relating to fixed spatial information, with the interaction of both being important in developing one’s spatial ability. For navigating complex environments, those with strong static spatial abilities rely on maps, whereas those with dynamic spatial abilities rely on real-time sensory input from the environment to navigate.

3.2 Spatial Skills & Spatial Visualisation

There is a direct link between spatial skills and spatial visualisation with almost all studies examining spatial skills dependant on using visualisation as a predictor of capacity. Over the years, clarification of its importance is evident in studies across the board; Newcombe (2013) identifies it as being directly related to the ability to interpret graphs and solve problems and Uttal (2012) explores its use in imagining the geometries of cut sections of three-dimensional objects and structures. There are also instances in which an object may be described as a flat surface (navigational map), requiring a greater level of skill to comprehend and visualise the described object (Lane and Sorby 2022). Spatial skills can be differentiated into two broad categories, small and large scale, with each category respectively drawing on different cognitive processes. Researchers have recently discovered a strong positive correlation between spatial skills and success in Science, Technology, Engineering and Mathematics (STEM) education (Cheng and Mix 2014; Lowrie et al. 2017). The development of spatial skills however continues to be a significant “blind spot” in many educational systems despite this significant research, with students worldwide entering third-level education with underdeveloped spatial skills (National Research Council 2006). These skills are malleable however, and can be improved in formal educational settings both directly and indirectly (Lane and Sorby 2022; Uttal et al. 2013). Some researchers also make reference to a ‘visuospatial’ ability which can be described as a specific type of spatial ability which emphasises visual processing skills (Lowrie et al. 2017; Aguilar Ramirez et al. 2020). Similarly, visuospatial thinking refers to the cognitive process of mentally manipulating and transforming visual and spatial information to solve problems (Hegarty and Stull 2012).

3.3 Spatial Intelligence

According to Gardner's multiple intelligence theory, first put forth in 1993, intelligence is not one unified skill but rather a group of different skills or intelligences that each function somewhat independently of one another. (Gardner 1993) claims that each person has a special combination of these intelligences, and that different people may excel in various fields. This theory, which contends that people can develop their strengths in various areas to achieve success in a variety of fields, has been extensively used in education and career development. Spatial intelligence can therefore be described as a person’s ability to think in three-dimensional space, visualise objects in different orientations and create mental images from information provided from the physical world. While spatial intelligence and spatial thinking are related, they are not the same thing. Individuals with high spatial intelligence may not necessarily have strong spatial thinking skills, and vice versa. However, the two concepts are often interrelated, as individuals with strong spatial thinking skills may be better able to apply their spatial intelligence to real-world tasks.

3.4 Spatial Thinking, Spatial Reasoning & Spatial Literacy

(Smith 1964) describes spatial thinking as being a fundamental skill within the STEM domain with its core links to spatial awareness, spatial reasoning, and spatial literacy. We often describe spatial thinking as a collection of cognitive skills used to represent, analyse and reason about objects, space and their relationship with the environment and in 2012, (Newcombe and Shipley) proposed a spatial thinking typology based on two dichotomous factors. The theory proposes that there are two different ways in which people can engage with spatial information: intrinsically or extrinsically. Intrinsic spatial information refers to information that is related to the objects or features themselves, such as the shape, size, and location of objects in a space, and can be processed independently of the viewer's position and orientation in relation to the objects. In comparison, extrinsic spatial information refers to information that is related to the viewer's position and orientation in relation to the objects and involves considering the viewer's perspective and the way the objects are arranged in relation to the viewer. Newcombe's theory has important implications for education and training in spatial thinking. By understanding these individual differences, educators and trainers can tailor their instruction to better meet the needs of learners with different spatial thinking abilities. Spatial thinking provides the foundation for spatial reasoning. The ability to mentally manipulate and visualize spatial information is critical for solving problems that require spatial reasoning. Both skills are important in many areas of life, from academic pursuits to everyday activities such as driving or navigating a new city.

Spatial literacy was found to be the least used term in spatial research over the last ten years with only four results noted. From these papers, spatial literacy can be commonly known as the ability to understand and interpret spatial information and to think abstractly and critically about spatial relationships. (Moore-Russo et al. 2013) made sense of this by identifying the three core components of spatial literacy which subsequently, add to research in the area without direct mention: spatial reasoning, spatial visualisation, and communication.

4 CONCLUSIONS AND FUTURE WORK

Spatial research is a complex area that has grown from the psychology discipline into the broader educational research arena in recent years. The complexity of the area demands careful unpacking, synthesis, and consideration especially at the beginning of research studies that aim to examine different nuances of how humans think about spatial concepts. This paper serves as a guide for both new and experienced researchers, through the clarification of core spatial terms ensuring that pertinent literature data is easily accessible to all. As seen from the flow diagram (*Figure 1*), there is not an equal distribution of research among areas, highlighting the need for researchers to look deeper into their area of spatial research. One reason as to why spatial ability studies have been published more often is due to the availability of objective metrics (such as mental rotations testing and paper folding testing) and the ease in which these can be analysed. Conversely, spatial thinking is much more nuanced and somewhat subjective in its measurement and accordingly it would require the use of interviews, observations to examine sketching skills, reflection on past experiences, beliefs, and values – as a result of this, there are less studies that have reported on such research. It is critically important that we, as educators, understand and appreciate these nuances in competencies to allow for spatial learning to be embraced fully into our educational systems resulting in a more sustainable, spatial education for all.

Figure 3 highlights synthesis of theory relating to spatial research in a mapping format, with the intention of encouraging both experienced and new researchers to understand what spatial learning entails more holistically. This framework also provides researchers with a comprehensive tool that can be used in mapping a sustainable approach towards an area of spatial research at any stage in their research careers. From conducting this study, developing and utilising the theoretical map of spatial research, future work will focus on the area of spatial factors and spatial ability with reference to the gender gap in engineering.

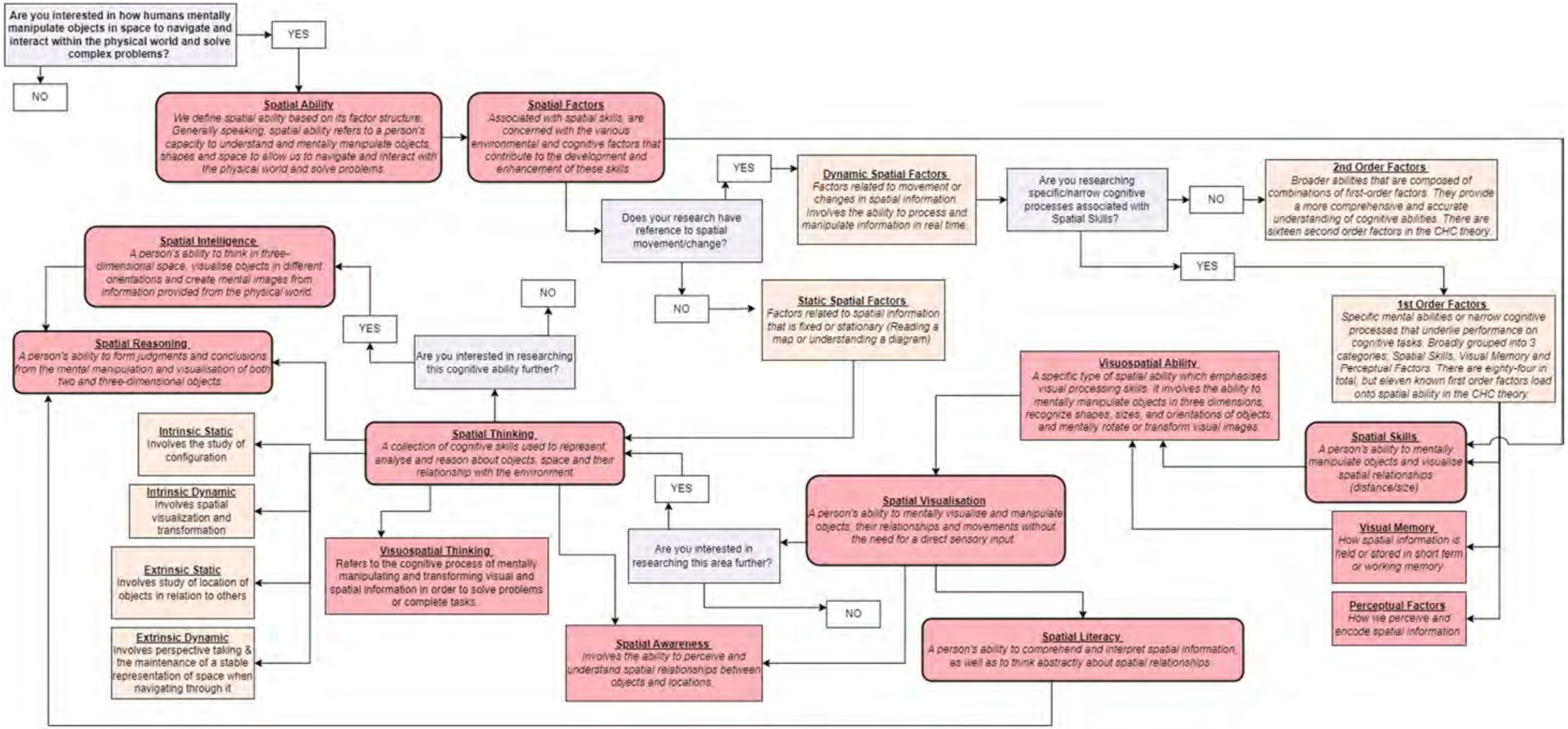

Figure 3. Theoretical Mapping of Spatial Research (2012-2022)

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Teaching Sustainability through a role-play case study of e-scooters on college campuses

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ABSTRACT

Sustainability has developed into a pressing concern across disciplinary domains, and the need for teaching sustainability concepts to students has grown significantly. In this paper, we present a research study that assessed undergraduate students' understanding of sustainability after participating in a case study discussion. We

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designed and implemented a role-play case study of e-scooters on a college campus. The case facilitated “near transfer,” as it focused on an issue most students have personally experienced. Furthermore, the role-play component simulated a real-world context and allowed students to take different perspectives related to the topic, resulting in a discussion of social, political, economic, and technical factors related to sustainability. The case study was implemented with 38 students. Course readings and pre-case study assignments were used by students to prepare for the role-play. Students participated in groups of 6-7 participants in student-led discussions. To evaluate the development of perspectives, we undertook a thematic analysis of the pre- and post-assignment questions using a framework derived from Transformative Learning Theory (TLT). Findings show that students developed a holistic view of sustainability by co-constructing decisions related to the case study presented. The role-play case study and role descriptions are presented in the Appendix.

1 INTRODUCTION

1.1 Background

The idea of sustainability has evolved from a purely environmental concern to a more multi-disciplinary challenge that requires a thorough understanding of socio-economic, political, ethical, justice, and equity implications (Bennett et.al 2019; Kidd 1992). Furthermore, as digitization has increased across all aspects of society, sustainability has also become intertwined with progress in computing technologies. The complexity of sustainability tends to be difficult for students to understand, and a largely linear or lecture-based form of teaching about sustainability is only marginally effective (Joslyn 2017; Van Wynsberghe 2022).

1.2 Study Aims and Research Questions

This study assessed how a role-play case study on the use of e-scooters on college campuses helped expand students’ understanding of the concept of sustainability (Johri and Hingle 2022; Hess and Brightman 2017; Maier, Baron and Mclaughlan 2007). We adopted transformational learning theory to analyze the outcomes of the intervention. Specifically, the study explored: 1) Does role-play simulation lead to transformative learning about sustainability; and 2) How do students’ experience of e-scooters on college campuses and discussions with peers transform perspectives about sustainability?

2 LITERATURE REVIEW

2.1 Toward a holistic point of view on sustainability and teaching sustainability

According to Kidd (1992), the earliest definitions of sustainability were in environmental terms. The primary narrative was the overconsumption of natural resources in light of urbanization and its effect on the earth’s carrying capacities. Over time, this viewpoint was widened, and sustainability was defined in terms of three pillars, i.e., the environment, the economy, and the society (Cuello Nieto and Neotropica 1997; Johri and Hingle 2022; Maier, Baron and Mclaughlan 2007). The Stockholm Conference in

1972 added the idea of ‘wellbeing’ for developed and developing nations to the definition (United Nations Foundation 2023). The Millennium Development Goals in 2000 and, recently, the Sustainable Development Goals (SDG) have further widened the scope with seventeen goals ranging from poverty and climate change to prosperity (WHO 2018). This new holistic approach to sustainability extends the three pillars of economic, social, and biological spheres to include institutions, governance, ethical aspects, and equity for all (Blewitt 2008; Caetano and Felgueiras 2019; Casañ, Alier and Llorens 2021; Maier, Baron and Mclaughlan 2007; McGill University 2023).

As the definition of sustainability has evolved to become multi-disciplinary, it has become increasingly complex. Studies point out that students find it difficult to understand the idea of sustainability(Feng 2012; Maier, Baron and Mclaughlan 2007; Salas-Zapata and Ortiz-Muñoz 2018; Steiner and Posch 2006). Consequently, instructors within engineering have developed and implemented different approaches to teach sustainability. For instance, Jeon and Amekudzi (2005) used a project-based approach that focuses on engaging stakeholders and encourages decision-making through consensus. An infrastructure component has also been used to guide class discussions (Maier, Baron and Mclaughlan 2007). The system’s approach model that addresses five components, i.e., socio/cultural, environmental, economic, technical, and individual, has also been employed (Pappas 2012). Overall, there is consensus that a productive way to address sustainability in classrooms is to build on students’ previous personal and professional experiences and encourage them to address real-life problems collectively (Caetano and Felgueiras 2019). Such a pedagogy is supported by Mezirow’s Transformative Learning Theory (TLT) (Mezirow 1991).

2.2 Transformative Learning Theory for teaching holistic ideas of sustainability

According to Mezirow’s TLT, learners evaluate past ideas and experiences as they get new information. This drives a shift in their worldview, making room for newer insights. Transformative learning occurs in phases, starting with a ‘disorienting dilemma’ when a learner finds conflicting ideas to past beliefs. This leads to the phase of self-examination, followed by a critical assessment of the assumptions formed as learners take on new roles. The focus of transformative learning is either on ‘instrumental learning’ that involves ‘task-oriented problem solving’ or on ‘communicative learning’ that explains how learners express intentions, values, and morals (Mezirow 1991; WGU 2020). TLT has also been adopted for teaching-learning of sustainability in engineering classrooms (Sipos, Battisti and Grimm 2008; Van Wynsberghe 2022).

Joslyn (2017) adopted Mezirow’s TLT to assess engineering students’ development of humanistic perspectives and suggested three evolving phases or stages of learning. The *engineering point of view* pointed out the presence of technocentric and positivist mindsets, the *new point of view* marked an intermediary step, and the *transformed point of view* reflected an understanding of the social nature of engineering.

One pedagogical device for teaching toward transformative learning is role-play scenarios (Johri and Hingle 2022). Role-play scenarios allow learners to work on real-world problems and scenarios as well as discuss and change perspectives through peer interaction (Johri 2021). The construction of role-plays and their implementation can be designed to provide the necessary scaffolding for students to learn complex topics and, especially, to work on problems that have no single and simple answer. Role-plays also provide a means to bring contexts with which students are familiar into the discussion, facilitating "near transfer" of learning, i.e., transfer of knowledge across similar or familiar contexts (Perkins and Gavriel 1992).

3 METHODOLOGY

3.1 Context and Participants

The role-play on using e-scooters was implemented in the College of Engineering and Computing at a large public university in the USA [see Appendix A & B for the scenarios, roles, and assessments]. The topics for the course included global economic history, global development, AI algorithms and fairness, and IT ethics. The objective of the course was to guide students toward developing a nuanced and contextual understanding of the design, implementation, and use of information technology.

The research study, approved by the Institutional Review Board (IRB), was undertaken with 38 undergraduate students majoring in technology courses (computer networking, information technology, cybersecurity) who participated in discussion groups of 6-7. All students completed pre- and post-class assignments. For this paper, assignment responses from consenting students were analyzed to understand sustainability concepts and changes in perspectives triggered due to the role-play.

3.2 Using role-play scenarios to transform students' understanding of sustainability

3.3.1 The role-play case study on e-scooters on college campuses

E-scooters are motorized stand-up scooters powered using a small electric engine. As a means of micro-mobility, e-scooters are being used as a convenient alternative to traditional gas-powered vehicles or public transportation. Over the past few years, e-scooters have become convenient for college students. However, recently college administrators are banning these scooters and other electric equipment due to safety concerns (Eggert 2020). The real impact and utility of e-scooters are also being contested. While some argue that e-scooters offer less pollution and cheaper mobility solutions, others point out the shorter lifespans of the scooters and issues with their disposal (Sipos and Battisti 2008). Since the issue and context of e-scooter use relate to students' own experiences on campus, a case study was designed to develop perspectives on sustainability. A central dilemma of allowing or banning e-scooters was presented. The case study uses a multi-stakeholder approach, where the roles are mapped to represent political, social, economic, technical, environmental, and ethical viewpoints. This helped learners empathize with distinct viewpoints pertaining to a real-life issue through discussion.

Pre-class readings based on a broad framework that considered political, environmental, societal, and other factors were provided to aid students' understanding of sustainability and assist in efficiently playing their parts for the role-play. These readings discussed different concerns, such as accessibility, regulation, and ethics, along with socio-economic and environmental issues (Casañ, Alier and Llorens 2020; DCosta 2010). Pre-class homework was assigned, prompting students to think about the dilemma and their ideas on sustainability and to familiarize themselves with the perspectives of all stakeholders. A post-class assignment with questions followed the role-play scenario and asked students about their recommendation, the group dynamics, lessons learned about sustainability, and changes in their perspectives.

3.4 Assessing students' learning

Student learning was assessed qualitatively using thematic analysis of pre- and post-class assessment responses. Themes were drawn inductively and deductively using concepts from Transformative Learning Theory (Braun and Clark 2012). Data were coded by two coders and checked for inter-coder reliability.

3.4.1 Changes in perspectives

Responses to pre- and post-class assignments were analyzed for change in perspective about sustainability. Based on TLT and Joslyn's (2017) classification of the three phases of perspective change among engineering students, changes in perspectives of students were thematically coded for learning in three phases as defined in Table 1.

Table 1. Exploring Students' ideas through Transformative Learning Framework

Points of view on sustainability (Guided by Transformative Learning Theory)	***Ideas Demonstrated***
Environmental points of view	Students mention only 'environmental' ideas.
Extended points of view	Students mention technical, economic or social dimensions of sustainability.
Holistic point of view	Students mention most of the political, social, technical, economic, ethical and regulatory aspects of sustainability.

3.4.2 Insights and "Aha-moment": E-scooters are "not as sustainable as [they] seem."

Coders analyzed responses to explore the insight or "aha-moment" - a sudden comprehension that helps reinterpret a solution. In working through the case and guiding questions, insights result from restructuring the elements in a situation or problem. Corresponding with the first phase of transformative learning, insights present a disorienting dilemma where learners find out the inaccuracy of their past beliefs

(Kounios and Beeman 2009). These “trigger events” act as catalysts for transformations and critical reflections (Mezirow 1991; WGU 2020). Responses were analyzed and coded for observed insights regarding sustainability.

3.4.3 “Near-Transfer” of Learning

“Transfer of learning” is interpreted as applying prior learning and experiences in novel contexts. According to TLT, as students begin to self-examine past beliefs, they think about previous experiences. The role-play scenario simulates the application of prior knowledge in a significantly similar context. This leads to “near-transfer” learning as students bring in their past ideas and transfer them to learn new ideas and perspectives (Perkins and Gavriel 1992). As the case study is based on a college campus, students’ everyday encounters with e-scooters, both the convenience and issues they present, are explored. Responses to pre- and post-assignments were coded for near-transfer.

4 RESULTS

4.1 Students were able to develop an extended and holistic point of view of sustainability

Forty-two percent of students demonstrated an understanding of sustainability beyond environmental terms (Fig.1). Students successfully formed connections between multiple perspectives presented and demonstrated a broadened point of view.

“Sustainability, I discovered, entails understanding and safeguarding the interconnected linkages between the environment, culture, and economy.” – Student 1

“*There are aspects of health, economic growth, and social wellbeing, data and public tools associated with sustainability*.” – Student 2

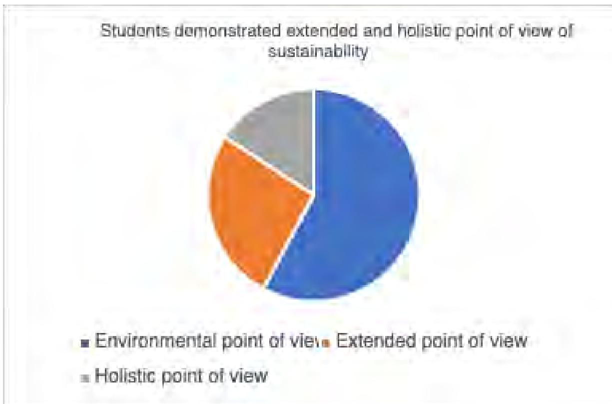

Fig. 1. Students demonstrated an extended and holistic point of view of sustainability.

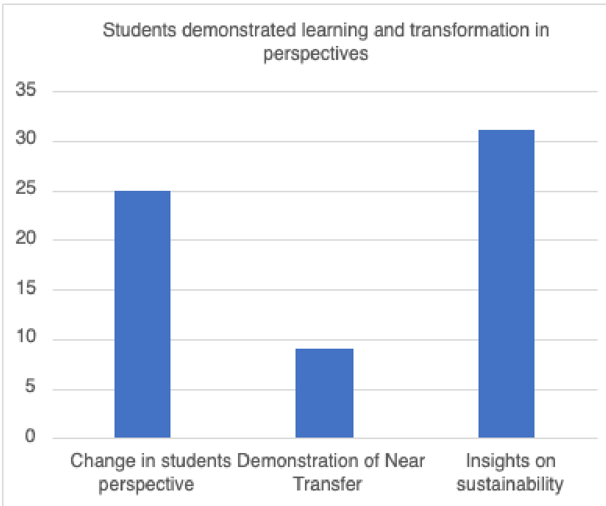

Fig. 2. Students’ perspectives changed with new insights.

4.2 Role-play simulation transformed students' perspectives and facilitated learning about sustainability.

Of 38 students, 81.5% reported a change in perspectives around sustainability. As students co-constructed knowledge with their peers, their understanding of sustainability broadened (Fig 2). The role-play allowed an improved understanding of an infrastructural decision to allow or ban e-scooters on campus. Students were able to evaluate the long-term impact of this decision. It should be noted that students demonstrated one or more changes in perspectives, near-transfer, and insights about sustainability that indicated learning and transformation of perspectives.

"*During the discussion, while I was listening to other group members, my perspective did change because I was able to create more ideas in my mind and was able to understand the idea of sustainability based on what others were saying*." - Student 3

"Yes, my perspective has changed because an e-scooter is not as environmentally friendly as I had initially expected. Although individual e-scooters are not very harmful to the environment, the biggest impact on greenhouse gas emissions comes from the resources and the businesses that work every day to locate all the scooters, recharge them, and return them." - Student 4

Table 2. Students point of view on sustainability changes in three phases

Theme	*Number of students*	*Example*
Environmental point of view	22	*"I learned that e-scooters are not completely eco-friendly but are better than fuel vehicles."*
Extended point of view	10	"*To decide whether to use an e-scooter or not, we need to consider the following factors – the carbon footprint, the cost of production, and the resources used for operation."*
Holistic point of view	6	*"Sustainability is a process. We need to think of social, economic, environmental, and wellbeing factors to design sustainable artificial intelligence systems."*

4.2.1 Students were able to demonstrate a 'near-transfer' of their own experiences with e-scooters and expand understanding about sustainability

Students were able to relate their own experiences of using e-scooters on campus to the case study, and they grappled with dilemmas around the personal convenience of using e-scooters and accidents or accessibility issues in the community at large.

It was interesting to note how students used the name of their own university instead of the one mentioned in the case study while responding to decisions during the role-play.

"As someone who lives on campus, I understand the use of scooters since [student's university] campus is so huge, but, I do believe they should not be used as I have almost been hit by the scooters and their riders because they were riding on the sidewalks and it does make me quite nervous to walk on sidewalks now." Student 5

4.2.2 Students were surprised to learn that the batteries used in e-scooters were not as environmentally friendly as they had assumed

Electric scooters are often considered “sustainable and eco-friendly” options that avoid fossil fuel consumption and help decrease CO2 emissions. However, issues like human rights violations, circulation accidents with pedestrians, and lack of end-of-life recycling processes are not addressed in the popular narrative around e-scooters (Rabino-Neira 2019). Most students were surprised to find out that batteries used in e-scooters have a short life and cause long-term environmental pollution. This finding also helped look beyond the often perceived “sustainable nature” of e-scooters.

“*I learned that even with things that would, in theory, highly support sustainability, it turns out that is not the case. Such as with batteries for the device and studies on them. They were not as environmentally friendly as we may think.” - Student 6*

“My perspective changed, because initially, I was only focused on whether a product’s operations were actively polluting, rather than its entire lifecycle.” Student 7

Table 3: Students’ perspectives changed and influenced learning

Theme	*Occurrences*	*Example*
Change in students’ perspective	25	*“My perspective did change. Earlier, I supported implementation of these scooters but did not think of other conditions that come with it.”*
Demonstration of ‘Near Transfer’	9	*“I agree with the resolution because we have scooters at our university as well and I can see the convenience behind them.”*
Insights on sustainability	31	*“I had no idea that e-scooters were not the most environment-friendly alternatives.”*

5 DISCUSSION AND LIMITATIONS

In this paper, we present a study that assessed whether role-play case studies can provide students with a more holistic understanding of sustainability and, specifically, allow them to learn from each other's perspectives. Toward this end, we developed a case study with which students could identify and have some experience. We found that, overall, students displayed evidence of both holistic thinking about sustainability and perspectival thinking. Consistent with TLT, students’ understanding of sustainability varies from a simpler, in this case, environmental view toward a more integrative view that considers other factors. Students also demonstrated near-transfer of the case study to their own institution. This study suggests a role-play approach's effectiveness in teaching a complex topic, such as sustainability.

The study presented here has certain limitations. We only report on a single course offering, and only students from technology majors participated in this study. It will be useful to expand to other disciplines to learn how those with a different domain knowledge address the scenario. It is also difficult to compare accurately what aspect of the scenario changed students’ perspective and what role the readings played compared to peer influence. Students’ deeper insights into sustainability can be better assessed through other methods, such as interviews. Finally, the study looks at a single role-play; long-term changes in students' perspectives have not been studied. Future work might use different role-plays in varied contexts around the theme of sustainability.

6 ACKNOWLEDGMENTS

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Appendix –A E-Scooter Case Study

E-Scooter Case Study

Eva Walker recently started reporting on-campus traffic issues for the student newspaper. She would have preferred to do more human-interest stories, but as a new member of the staff who had just moved from intern to full-time, she was happy to get whatever opportunity she could. Eva was a double major in journalism and creative writing, and this was her dream on-campus job. She also realized that, even though many stories at first didn't appear to her as though she would be interested in them, as she dug deeper she eventually found an angle with which she could strongly relate.

One weekday morning, Eva was working on yet another story on parking woes when Amina Ali, one of the editorial staff members, texted her to say that there had been an accident on campus; she just passed it at the intersection of the library and the recreation building, and it might be worth covering. Eva was at the library, and within no time, reached the spot of the accident.

When Eva arrived, a patrol car, an ambulance, and a fire engine were all present at the scene, and near the accident site, an e-scooter lay smashed into a tree. The rider, it looked like, was sitting in the ambulance and was being treated by the medical staff. A little further down, Eva noticed the police speaking to a young woman in a wheelchair. Although Eva's first instinct was to try to talk to the police or the medical staff to ascertain what had happened, she realized this probably wasn't the best moment and she would have to wait until later for the official version of the event.

She looked around and saw a group of four students leaning against a wall with drinks in their hands. A couple of them were vaping. Eva thought that they looked like they had been here for a while, and she walked over to ask them what had happened. From the account they gave her, it appeared as if the e-scooter rider was coming around the bend at some speed, saw the woman in the wheelchair a little too late to ride past her, and, to avoid hitting her, leapt off his e-scooter and let the vehicle hit the tree. Things happened very quickly and no one was exactly sure about the sequence of events, but this was the rough story she got.

Later, she called the police department on campus and was able to speak with one of the officers to get an official account. The story was very similar to what she already knew. She did find out that nobody was seriously hurt and that the only injuries were to the e-scooter rider and were taken care of at the scene by the medical staff. When she asked about who was to blame or if any legal action was expected, she was told that there were no laws around the use of helmet or speeding for e-scooters yet and that she should reach out later for more information. Eva wrote up what she had so far, sent it over to the editorial staff, and called it a day.

As she was walking back to the dorm that evening, her attention was drawn to the large number of e-scooters parked near the library. As she crossed the central campus, she noticed even more e-scooters lying about the intersections, and there was a litter of them around the dorm. She wondered why she hadn't noticed them before. Her attention was drawn today, she thought, because of the accident and also because she saw a good Samaritan remove an e-scooter from the sidewalk, as it was blocking the path of one of the self-driving food delivery robots. It's a sign, Eva thought, this is what she needs to look for more in her next article, the use of e-scooters on campus.

Eva recognized that, to write a balanced and informative article, as she had been taught to do, she would have to look at many different aspects of the use of e-scooters as well as look broadly at mobility on campus and the use of battery powered vehicles. She had also recently seen e-bikes on campus and, in addition to the food delivery robots, service robots in one of the buildings that she assumed was either delivering paperwork or mail. The accident had also made her realize that, when it came to mobility, accessibility was something that never crossed her mind but that she now understood was an important consideration. She hoped to learn more about it as her research progressed.

As background research for the article, Eva started reading up on articles and studies published about e-scooters, e-bikes, and urban mobility and came across a range of concerns that had been raised beyond accessibility. First, there were reports that e-scooters are not as environmentally friendly as many service providers had made them out to be. This is related to the production of the battery as well as the short lifespan of the vehicles, and as of yet, there has been no procedure implemented to reuse them[2]. Second, there were reports of littering, where e-scooters are often left on sidewalks and other places where they restrict movement of other vehicles, pedestrians, and in particular, those in wheelchairs[3]. Finally, it was also clear from the reports that accidents and injuries have increased due to e-scooters, especially since many riders do not wear safety gear and are often careless, even inebriated, as there were little to no regulations[4]. When she approached her editor with an outline for an article, she was advised to do some more reporting by talking with people who could shed more light on the issue.

After some research, Eva shortlisted the following experts across fields related to e-scooters for an interview, and once she spoke with them, she realized that it would help her if she could get them to have a dialogue and respond to some of the questions that were raised by other experts. Therefore, she decided to conduct a focus group with them so that she achieved her goal of a balanced article and did not misrepresent any expert's point of view.

1. **Bryan Avery is co-founder and Chief Technology Officer (CTO) of RideBy, an e-scooter company.** RideBy is one of the options available on campus. Born in a small town, Bryan used to ride his bicycle everywhere while growing up, and for him, founding and leading an e-scooter company provided a chance to merge his interests in personal transportation and new forms of energy. He was a chemical engineer by

[2] https://www.smartcitiesdive.com/news/reduce-reuse-rescoot-a-look-at-e-scooters-long-term-sustainability/558691/

[3] https://wtop.com/dc/2021/09/upcoming-dc-law-aims-to-stop-e-scooters-from-littering-sidewalks/

[4] https://www.safetyandhealthmagazine.com/articles/21536-weekend-drinking-a-factor-in-many-e-scooter-injuries-researchers-say

training, and at a time when most of his friends ended up working for big oil companies, Bryan decided to work on alternative fuels and found himself developing expertise and experience with batteries. For most of the software- and mobile device-related development, RideBy outsourced the work and utilized ready-to-configure systems that were available. By only keeping the core device and battery functionality in-house, they could focus on delivering a much stronger product. Overall, he is quite happy with the success of RideBy so far and can't help but extol the difference it can make for the environment.

2. **Abiola Abrams is a professor of transportation engineering and an expert on mobility systems**. Her work combines systems engineering, computer science, and data analytics. Her recent research is on urban mobility and micro-mobility services, particularly e-bikes. In her research, Dr. Abrams has looked at a host of topics related to e-bikes, many of which are also applicable to e-scooters, including the optimization of hubs for availability, common path patterns of users, subscription use models, and the e-waste and end of lifecycle for these vehicles. Increasingly, she has become concerned about the abuse of some of these services, especially in cities that attract a lot of tourists, and about the rough use of the vehicles, so much so that many do not even last for a month. In a new project, she is investigating the effect of e-vehicles on the environment and has found that there is mixed evidence for how much difference battery-operated vehicles will actually make for climate change compared to vehicles that use fossil fuels.

3. **Marco Rodrigues works as Transportation Director for the local county government where the university is based.** As part of a recent bilateral international exchange, he got the opportunity to spend time in different cities in Germany to learn about local transportation. He realized very quickly that local transportation was very different in Germany; residents had a range of public, shared options that were missing in the United States. However, he also realized that e-mobility services were being considered across both countries. He investigated this further and found that Germany waited until it could pass some regulations before allowing e-mobility operators to offer services; helmets were mandatory on e-scooters and e-bikes, and riders had to purchase a nominal insurance policy. He also learned that there were strict rules around the sharing of data generated by the vehicles as well as the apps used by riders.

4. **Judy Whitehouse is Director of Infrastructure and Sustainability** on campus and responsible for planning the long-term development of the campus from a space perspective, but also increasingly from a sustainability dimension. As the number of students has increased, so has the need for more infrastructure, including classrooms and dorms. This has also resulted in greater distances to be traveled on campus. Judy regards e-mobility options as a necessary component of campus life and has been a strong supporter for them. Lately, she has been called into meetings with safety and emergency management people discussing the issue of increased accidents on campus and the littering of e-vehicles across the campus. Not only is it bad for living on campus, but it is also bad optics. A recent photo featured in the campus newspaper

was a stark reminder of just how bad the optics can be. She is further divided on the use of e-scooters due to misgivings about the sustainability of battery use, as new research suggests that manufacturing batteries and disposing them are extremely harmful for the environment.

5. **Aaron Schneider heads Campus Mobility, a student interest group focused on autonomous vehicles development and use**. The group members come from different majors and are interested in both the technical dimensions of mobile solutions and the policy issues surrounding their implementation. Aaron himself is a computer science student with interests in data science, and with some of his fellow members from the policy school, he has been analyzing a range of mobility-related datasets that are publicly available online. Of these, the data on accidents is quite glaring, as the number of accidents in which e-scooters are involved has gone up significantly. Aaron and his friends were intrigued by their findings and approached some of the companies to see if they would share data, but they were disappointed when they could not get access. Although the companies said it was due to privacy reasons, Aaron was not too convinced by that argument. He was also denied access to any internal reports about usage patterns of accidents. Ideally, he would have liked to know what algorithms were used for optimizing delivery and access, but he knew he was not going to get that information.

6. **Sarah Johnson is the Head of Accessibility Service**s on campus and is responsible for both technology- and infrastructure-related support for students, faculty, and staff. The growth of the physical campus and the range of technological offerings has significantly increased the workload for her office, and they are really strained in terms of people and expertise. The emphasis from the university leadership is largely on web and IT accessibility, as teaching and other services are shifting quickly online, but Sarah realizes that there is still an acute need to provide physical and mobility support to many members of the community. Although all the new buildings are up to code in terms of accessibility, there is still work to be done both for the older buildings and especially for mobility. Campus beautification does not always go along with access. She is also worried about access to devices, as taking part in any campus activity requires not just a computer, but also access to mobile devices that are out of reach economically for many and not easy to use.

To help get the dialogues started and based on her prior conversation with the group, Eva has prepared some initial questions [these can be used as discussion prompts]:

1. From your perspective, what do you see as the biggest pros of using e-vehicles, especially e-scooters on campus?
2. From your perspective, what do you see as the biggest downside of using e-vehicles, especially e-scooters on campus?
3. Can you confidently say that e-scooters are an environmentally friendly option?
4. What current accessibility accommodations would be impacted by the use of e-vehicles, and what new, potential accessibility accommodations might arise from increased use of e-vehicles?

5. Would we be better off waiting for more regulations to come before deploying these vehicles on campus and, if so, what should those regulations look like?
6. Should we use automatic regulation of speed on the vehicle based on where it is and/or inform authorities if it is violated?
7. Can we control where it can go or penalize if not put back?
8. What guidelines do you recommend for e-scooter usage on campus?

Appendix –B Pre/Post assignment questions

Pre-assignment questions:

1. From your perspective, should Eva write in favor of e-scooters on campus or against their use; why/why not? What are some issues she will need to keep in mind while writing her article?
2. From your perspective, what sustainability considerations should influence the decision to use e-scooters or not?
3. From the perspective of each of these roles, what would you recommend to Eva Walker and why?

Post-assignment questions:

1. What recommendation did your group reach following the discussion, and what criteria were considered?
2. Was the recommendation agreed to by all or did one person have more influence? Why? Do you personally agree with the solution reached? Why/Why not? Any comments on how your group approached the case?
3. What did you learn about sustainability as part of this role-play discussion? Did your perspective change?

Exploring racialized ideologies about Latino/a/x Engineering Students in the United States Southwest Region

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ABSTRACT

Although efforts in the United States (U.S.) to improve the participation and representation of minoritized populations in engineering have increased, there is a stagnant representation of Latinos/as/xs in engineering spaces. Given that a historical context of engineering education for Latinos/as/xs in the U.S. is limited in the engineering education research literature, this paper provides a description of the historical educational landscape of Latinos/as/xs in the U.S. Southwest region and connects that sociohistorical context to the current realities of Latinos/as/xs in the region through their *testimonios*. The U.S. Southwest is home to the largest Latino population in the U.S., who also happen to be predominantly, and historically, Mexican and Mexican American. Thus, this research paper focuses primarily on this region since it is also the location where most of the Latino/a/x engineering students reside and attend school. This paper draws from the theoretical framework of racialization to explore the ways in which racialized ideologies about Latinos/as/xs emerged from an orchestrated process of Americanization, linguistic violence, and deficit thinking that continues, to this day, to impact Latino/a/x engineering students. Implications of this study suggest that recognizing the role of racialized ideologies in shaping engineering education spaces may serve to help engineering educators

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identify the ways in which historical and sociopolitical forces are (re)enacted, perpetuated, but also challenged.

1 INTRODUCTION

1.1 Historical Racialization in the U.S. Southwest

The thought of Manifest Destiny in the United States led to the ideology that Americans must move westward to spread their ideas of American exceptionalism. It was this principle that led to the annexation of Texas and the eventual Mexican American War of 1846. These events also shaped the social dynamics of the U.S. Southwest and the educational landscape that – to this day – continues to impact Latinos/as/xs[2] in the region. At the time, a large number of Mexicans and Mexican Americans inhabited in the U.S. Southwest and were part of a thriving community. After the Mexican-American War ended in 1848, Mexicans who remained in the United States were promised citizenship under the Treaty of Guadalupe Hidalgo. However, as the law at the time only allowed white individuals to obtain citizenship (black slaves in the U.S. were not considered citizens at the time), Mexicans had to be classified as white to receive citizenship, effectively racializing them (Donato and Hanson 2012). Nevertheless, in the eyes of the new settlers, Mexicans and Mexican Americans were not considered white socially. That is, Mexicans and Mexican Americans were white on paper but socially non-white, thus, relegating them to a second-class citizen status (Donato and Hanson 2012; Menchaca 1997).

This racialization process became even more apparent as Anglo settlers took control of policies that were harmful to Mexicans and Mexican Americans (San Miguel 1999). The settlers believed in converting them into American exceptionalism through a process of Americanization, and encouraged this process through English-only education and emphasizing a common American identity (San Miguel 1999). Eventually, the process of Americanization along with language subtraction, IQ testing, and vocational training were used as justifications to create segregationist practices that led to differential education between 1880 and 1930 (Gonzalez 2013; MacDonald 2004; Valencia 2010a). Although there was some resistance from the Mexican and Mexican American community, primarily through the establishment of their own *escuelitas* that supported bilingual education, the pervasive policies began to dominate the educational discourse in the region (San Miguel 1999; MacDonald 2004; San Miguel 1987; Goetz 2020).

1.2 Americanization and Racialization

The Americanization project in schools has traditionally viewed cultures of individuals who are considered to be on the margins of engineering, such as non-whites and non-Europeans, as destabilizing forces (MacDonald 2004; Blanton 2003). This has resulted in deficit ideologies (i.e., the idea that students come to school with inherent deficits from home) and racialization, leading to an assimilation process through subtractive schooling that aims to strip away language and culture from these

[2] In this paper, I use the term Latino/a/x as an all-encompassing inclusive term to refer to individuals that self-identify with any (but not limited to) of the following categories of Latin-American descent: Latino, Latina, Latinx, Chicano, Chicana, Chicanx, Hispanic, Latin American, Mexican American, Mexican (Villanueva Alarcón et al. 2022).

students. In the past, schools, including institutions of higher education, have taken a top-down approach to Americanize classrooms by propagating stereotypes and tropes about Mexican Americans, such as laziness, violence, dirtiness, lack of ambition, and promiscuity (Valencia 2010b, 1997; Valencia and Solórzano 1997). Teachers were taught to Americanize students, and classrooms became places where children were expected to emulate "desirable behaviors" while ridiculing their own traditions, racial identities, and culture (Blanton 2003). One example of this Americanization process is the presentation of engineering to Latino/a/x students through Western-oriented, rigorous, value-neutral ideologies, promoting capitalism, objectivism, and meritocracy as the values that all engineers should adopt (Cech 2013; Slaton 2015; Riley 2008, 2017), while at the same time ignoring other ways of knowing, doing and being (Mejia et al. 2018; Wilson-Lopez et al. 2016).

The Americanization process, as described by Valencia (1997), has been rooted in racist discourses that were intertwined with economic and colonial interests, leading to the racialization of Latinos/as/xs and the creation of a system of advantages and disadvantages (Menchaca, 1997). These interests became part of sociopolitical forces that restricted access to bilingual education, imposed tracking, and reduced school funding, resulting in negative impacts on the education of Latinos/as/xs, which we still see in engineering education today. This paper draws from the concepts of deficit ideologies and racialization to explore how these continue to exist in engineering spaces and how they impact students' lived realities. The paper is guided by the question: *How and in what ways do Latino/a/x students in the U.S. Southwest continue to experience racialization in engineering education?* The purpose is to reveal how political, historical, personal, and educational spheres are interconnected, where clashes occur, new meanings are made, and identities are formed.

2 THEORETICAL FRAMEWORK

2.1 Racialization as a Theoretical Framework

Racialized ideologies are beliefs, attitudes, and practices that assign different values and opportunities to individuals based on their perceived racial identity (Bonilla-Silva and Forman 2000; Zuberi and Bonilla-Silva 2008). These ideologies are often rooted in historical and social contexts and can perpetuate systems of oppression and inequality. Some examples of racialized ideologies include colorism, which values lighter skin tones over darker ones, and white supremacy, which promotes the belief that white people are inherently superior to people of color (Dixon 2019; Charles 2021). Some of these beliefs also include the idea that English (in the U.S. context) should be the *lingua franca*. Racialization is also the "racial logic that delineates group boundaries" (Gonzalez-Sobrino and Goss 2019, 507) to determine "otherness." Rosa (2019) argues that racialized ideologies are not just abstract beliefs, but are enacted through language and other forms of communication. These can be reinforced through media, everyday discourses, actions, education, and other cultural institutions. They can influence access to resources, such as education and healthcare, and contribute to disparities in wealth and power (Bonilla-Silva 2017). In this paper, I use the theoretical framework of racialization to demonstrate the ways in which Latino/a/x engineering students continue to confront racialized ideologies in the U.S. Southwest as the result of the historical influence of the Americanization process, particularly in terms of negative perceptions of Latinos/as/xs, their apparent academic ability, and linguistic practices. I also use these concepts to demonstrate the inner agency of these students and the ways in which they reject dominant discourses as they move through their engineering programs.

3 METHODOLOGY

3.1 Context of the study

This paper, which is part of a larger study, analyzes data collected from a multi-sited case study that was conducted at four universities (three public and one private) in the U.S. Southwest classified as Hispanic Serving Institutions and Emerging Hispanic Serving Institutions (meaning at least 25% of the students population self identifies as Latino/a/x) during the years 2020 to 2023. The universities are located in Texas and California, the states that currently serve the largest number of Latino/a/x engineering students. These locations were chosen because they have the highest populations of Mexicans, Mexican Americans, Chicano/a/x, and Latino/a/x individuals in the region, and because historical local policies and political actions have affected education for these groups (Valencia 2008). Although the student populations at each institution are diverse, the engineering programs follow similar accreditation rules, disciplinary norms, institutional structures, and curricular cannons. The study recruited 22 self-identified Hispanic and Latino/a/x engineering undergraduates who expressed interest in contributing to research about Latinos/as/xs in engineering. Most participants were first-generation college students of Mexican descent, with some using terms like Latino/a/x, Hispanic, or Mexican American to identify themselves; thus, demonstrating the diversity that exists within the Latino/a/x community (Revelo, Mejia, and Villanueva 2017). The participants came from various engineering disciplines, with mechanical and biomedical engineering having the highest representation.

3.2 Data collection and analysis

Although the larger study utilized various data sources, including *pláticas* (Guajardo and Guajardo 2013), focus groups, document analysis, and community walks, this paper focuses mainly on data from *pláticas* with participants. As the principal investigator, the author of this paper conducted individual meetings with participants in the form of *pláticas* to establish a relationship of trust between the researcher and the participant (Guajardo and Guajardo 2013; Saavedra and Esquierdo 2020). *Pláticas* resulted in *testimonios*, which are first-hand accounts of lived experiences voiced from the critically reflexive perspective of the participant (Beverley 2004; Delgado Bernal, Burciaga, and Carmona 2017; Delgado Bernal, Burciaga, and Flores Carmona 2012; Huber 2009). The *pláticas*, which lasted from 40 to 90 minutes and were conducted in both English and Spanish, explored various aspects of the participants' upbringing, education, and experiences in engineering. The resulting *testimonios* were then de-identified to ensure confidentiality and transcribed verbatim using Sonix. These transcriptions were then coded using NVivo 12 to identify recurring topics and themes that shed light on the intersection of language, gender, education, and culture in the participants' engineering journeys. These intersections were important because they are telling cases of the instances of racialization experiences by the participants (Rosa 2019; Flores and Rosa 2015; Zentella 2017). The themes are described in the results section, along with *testimonio* excerpts that illustrate the surface actions impacting the experiences of Latino/a/x engineering students.

3.3 Researcher's positionality

I identify as a Mexican American engineering educator who comes from a low-socioeconomic background, and I am also bilingual in Spanish and English. I have experienced racialization myself through schooling in the U.S. Southwest in the form of educational differentiation when I was not allowed to take upper-level math because of my "broken" English, and in engineering for not being considered a "true" engineering because of my ethnicity. These experiences helped me frame the research I present here and provided me with the tools to engage in a more humane research approach that honors the linguistic practices of the participants. My aim is to amplify the voices of Latino/a/x engineering students, recognize them as creators of knowledge, and (re)frame educational equity in engineering. I reject the idea that these students have inherent deficits that must be *fixed* because this kind of thinking marginalizes them instead of creating a supportive environment for them. I advocate for acknowledging and honoring the lived experiences of those who have been historically left at the margins, and integrate decolonizing research methodologies to promote liberative practices in engineering education.

4 RESULTS

Data analysis showed that participants encountered in their engineering pathways instances of racialization through the enactment of different actions, beliefs, and attitudes of others. The findings suggest that issues like racialization of ethnic identities, questioning of ability, and language subtraction continue to permeate education in the U.S. Southwest and negatively impact Latino/a/x engineering students. The following sections provide an overview of the results obtained from the analysis of the data. Please note that the participants self-identified for this study and those terms (i.e., Hispanic, Latino, Mexican American, etc.) are used to describe the participants and their *testimonios*.

4.1 Racialization of identities

One of the common racialization experiences the participants talked about involved confronting racialized ideologies with teammates when working in groups. Carlos, a Mexican American electrical engineering student, for example, commented on the questioning that he received constantly when working with other white classmates:

I can't say that it's specifically because I'm Mexican or not, but – In that situation, I guess I would like to believe so…But I can definitely say, like, there's been cases where I wanted to work with people and they've given me like a look, a smirk, or a mark. I'm not sure if it's because, like, the way I'm dressed, the way I look, maybe the color of my skin. Like, I never got those questions, but I never really cared. I never really cared. I just kind of like, okay, whatever. Like, I'll go work somewhere else, and then I just do my own thing

Carlos mentioned how racialization often took the form of actions and attitudes (e.g., looks, smirks, marks), as well as constant questioning of others about their presence in that space. While these events may have had a negative impact on Carlos, he decided to move on and do work on his own.

Other participants mentioned the racialization of their identities based on their looks and the general idea in the U.S. context that race is a black/white binary (Donato and Hanson 2012). This perception also ignores the fact that Latinidad is not within that black/white binary, but it exists in a complex system that cannot see beyond that framing. Eva, a Honduran American biomedical engineering student, commented on the issue of this binary and the questioning of Latinidad:

I tell people that I'm Hispanic. And then a lot of the times I get the question: how? Because I don't look like it. And then I have to explain to them, I guess you could say it's like, "oh, both of my parents are from Honduras, but, like, there's white and black here in Honduras – there's white and black over there. And my dad's black and my mom's white." But they were both born in Honduras. Born and raised in Honduras.

4.2 Questioning of ability

Participants indicated that they were constantly policed and question about their abilities in engineering. Following the old tropes and stereotypes of "laziness" and "lack of intellectual abilities" (Valencia 2010b, 1997), participants confronted the idea that Latinos/as/xs did not have the knowledge or abilities to engage in engineering. For instance, Nuria, a Mexican American general engineering student, commented on the actions and attitudes encountered in her computer science class:

My first computer science class was with Dr. [Kahn] and it was fine…prior to college, I had four years of experience in coding. So, I felt like going into that class I was going to do very well and I did do very well. But, I guess, I kind of wish that he was…he acknowledged my experience more. I felt like he like favored a lot of the, I guess, like, white students over me.

She later went on to comment as she tried to answer questions in class, she was constantly dismissed in favor of white male students. She observed what she described as preferential treatment and rarely acknowledged the insights she provided in class resulting in frustration, anger, and the belief that she did not belong in engineering.

In a separate *testimonio*, Santi, a Latino mechanical engineering student, reflected on the negative experience he had in a laboratory with a graduate student when the graduate student tried to challenge his knowledge about chemistry:

> *The first time I joined a research lab, a PhD student – he was very demeaning – he would tell me my data is crap. And I remember that time when he grabbed a pencil and told me "show me that you can do this calculation" – of like, a molar concentration – "show me that you can actually do this, because I don't think you can." Here I am like my first time trying to do research, and really trying my best, and he is like telling me, like, "you are not a researcher, you can't do this, if you show me you can do this then we can proceed." So, I am scared of coming into the lab.*

4.3 Language subtraction

Another theme in the data was that of language subtraction (San Miguel 1999; Ek, Sánchez, and Quijada Cerecer 2013; Martinez 2017), where students noticed the discriminatory undertones toward speaking languages other than English. Not only was speaking Spanish at home a point of contention for educators, but the fact that participants also spoke other indigenous languages at home. For example, Lara, a Mexican American environmental engineering student, reflected on how her teachers told her mother not to speak to her in another language that was not English because she would get "confused:"

> *So, growing up [the language spoken at home] was only Spanish. A little bit of English. Only when I had to do homework. Sometimes my mom speaks in Otomí, which is something I grew up talking, but I don't talk it anywhere just because, like, in elementary school, one teacher told my mom like, "Oh, she's not going to learn English and she's not going to do well in school if you keep teaching her another language," which I find it funny because by the time you get to high school, you need to have that, like, that credit of having another foreign language. And I was just like, why? Why do they do this to us? Why surpass us?*

This excerpt shows the long-held Americanization belief that language confusion can happen when growing up in a bilingual home (MacDonald 2004; Zentella 2017). It is also important to note that participants in this project recognized the dissonance that exists because students are asked to fulfil a second language requirement for graduation, but only Indo-European Language classes (i.e., French, Portuguese, German, etc.) are offered and credited as second language. Lara's experience was one common trend among all participants where language subtraction and policing were common. Moreover, it is important to note that the presence of Spanish as the only language (besides English) spoken at home has changed over the years. The U.S. Southwest demographics have changed and more indigenous languages are present. For instance, in this study, there were at least 6 participants that indicated speaking indigenous languages at home including Mixteco, Zapoteco, Maya, Otomí, Qhechua and Garifuna.

Another impact of historical language subtraction in the region was the fact that participants lost the learning of the language because of repressive actions in schools. Alberto, a Hispanic mechanical engineering student, reflected on the implications of historical language subtraction:

> *Growing up my mom was very fluent with Spanish and English, but she only talked to us in English, which was a bummer because now I struggle and I don't speak Spanish…I know back in the early or within the 1950s, the mid 1900s, that it was still in school, like, you couldn't speak Spanish, a lot of the students, they really – I mean, of course, white students and teachers really pushed for students not to speak Spanish in school. And I know even some people got picked on for it. You know, one of my aunts, two of my aunts actually got picked on for it. So, they stopped speaking Spanish altogether at school.*

5 DISCUSSION

The study suggests that Latino/a/x engineering students continue to face racialization in engineering spaces, particularly evident instances of "otherness" (Gonzalez-Sobrino and Goss 2019). As the world of U.S. engineering continues to be dominated by Americanization ideals of meritocracy (Cech 2013; Slaton 2015), rigor (Slaton 2010; Riley 2017), objectivity (Cech 2013, 2014), competitiveness (Faulkner 2007; Tonso 2007, 2006), and hypermasculinity (Tonso 1996, 2007; Faulkner 2000; Hacker 2017), Latino/a/x engineering students will continue to confront racialized ideologies about who engineers are and who they should be. Recent decisions by the Supreme Court of the United States regarding affirmative action (Nadworny 2023) will widen even more the gap that has been created in higher education rooted in historical racialization.

As shown by the results, participants continue to encounter issues related to the subtraction of language and linguistic practices in higher education, and have to confront the perception that English proficiency is often necessary to excel academically. The data also shows that racialization is complex and multifaceted, showing that it is not something from the past and that it is still very alive in the U.S. Southwest. Latino/a/x engineering students also experience the results of decades of the Americanization process, such as historical discrimination, language subtraction and schooling differentiation (Valenzuela 2010). The old tropes and stereotypes such as portraying Mexican Americans as lazy, criminal, and uneducated (Gonzalez 2013) are still present in engineering spaces, as indicated by the *testimonios* of the participants. Language discrimination and perceived accents (Flores 2019) have also been subject to discrimination and prejudice, with the particular banning of the use of Spanish and indigenous languages in schools as indicated by participants like Lara and Alberto.

Latino/a/x engineering students were also often excluded from the category of "engineer" – as demonstrated by the testimonios of Nuria and Santi – where their legitimacy in engineering was often questioned as well as their ability, and were instead assigned a racial category based on their perceived ethnicity or nationality. San Miguel (1999); Valencia (2010a) argued that these instances of questioning of intelligence come as a result of old tropes where IQ testing was utilized to frame Mexican Americans in the U.S. Southwest as unable to perform academically due to their perceived deficits. These examples illustrate how Latinos/as/xs have been and continue to be racialized in the U.S. Southwest, and how these processes have had a profound impact on their experiences and opportunities in society.

6 SUMMARY

The study suggests that racialization in the U.S. Southwest is a process that continues to impact how Latinos/as/xs reach educational parity and equity in engineering spaces. The research also provides a description of the *testimonios* of Latinos/as/xs that *are currently enrolled* in engineering programs. This paper also invites those who are currently serving Latino/a/x engineering students, to engage in reflexive practices to critically analyze the role that deficit ideologies play teaching, how we perceive students from multicultural backgrounds, and whether or not we create spaces where linguistic practices are valued instead of being silenced. It is also an invitation to Hispanic Serving Institution and emerging Hispanic Serving Institutions in the U.S. Southwest to analyze what servingness constitutes (Garcia 2020), the role of bilingualism in engineering education, and the support systems that are created to provide equitable access to engineering.

If the goal of engineering education in the U.S. Southwest is to broaden the participation of Latinos/as/xs, then we must (re)examine how ideologies, behaviors, policies, conventions, and norms in engineering intersect and shape the trajectories of Latino/a/x engineering students. This study emphasizes the need to understand the racialized experiences of Latino/a/x engineering students to provide better environments for learning and professional development. The sociopolitical realities of Latino/a/x engineering students are shaped by the negative stereotypes and policies developed toward Latinos/as/xs. The study calls for institutions of higher education, as specifically engineering, to reconsider how deficit ideologies emerging from racialization impact students. Challenging our own racialized ideologies – regardless of geographical location – is an act of resistance to ensure that engineering educators and institutions are accountable for their actions. Future work emerging from this research study will provide professional development workshops for faculty, students and staff that engage participants in reflexive practices to ameliorate the impacts of racialization and deficit ideologies through pedagogy.

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THE CHALLENGE OF POSTDOC’ING IN THE US: PERSPECTIVES FROM INTERNATIONAL ENGINEERING POSTDOCTORAL SCHOLARS

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ABSTRACT

An intrinsic case study explores the challenges shared by international engineering postdoctoral scholars about working in the United States (US). Little research has been devoted to their experiences despite their stark increase in the postdoctoral labor force over the last decade. Semi-structured interviews were conducted with eight engineering postdoctoral scholars hailing from Canada, China, Colombia, Iran, Italy, and Thailand. Participant interviews were analyzed inductively and resulted in four themes: (1) Immigration concerns; (2) Strains to find a community; (3) Pressure to publish and secure funding; and (4) Inadequate career counseling. The identified themes could be particularly instructive to Ph.D. advisors outside the US whose students may pursue postdoctoral positions in the US, Ph.D. recipients, US postdoctoral advisors, and US college and university international offices.

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1 INTRODUCTION

1.1 Overview

Understanding the challenges shared by international engineering postdoctoral scholars about working in the United States (US) may be critical to ease the difficulties they experience and to support their career success. Over half of science, technology, engineering, and mathematics (STEM) postdoctoral scholars in the US are from abroad (Camacho and Rhoads 2015); therefore, focusing on their challenges will greatly benefit the American postdoctoral labor force. An intrinsic case study design is employed to inductively explore interviews conducted with eight international engineering postdoctoral scholars. The research question guiding this study is: What challenges do international engineering postdoctoral scholars experience in the US?

1.2 Literature Review

Postdoctoral positions are increasingly considered necessary for STEM Ph.D. recipients seeking tenure-track faculty positions (Yadav and Seals 2019). As academic positions have declined, the volume of postdoctoral positions has increased. International Ph.D. recipients are attracted to postdoctoral positions in the US due to the high caliber of research occurring in the US (Cantwell 2011) and the availability of positions (Lee 2013). Employing international postdoctoral scholars diversifies American academic ranks and furthers world-class research (Cantwell and Taylor 2013). Considering international scholars comprise a substantial part of the US academic labor force, understanding their challenges is essential.

Before setting foot on US soil, international postdoctoral scholars must secure a work visa to be employed in the US (Ukachukwu et al. 2022). While American colleges and universities have relative flexibility in sponsoring H1-B visas for skilled immigrant workers in specialty areas and J1 exchange visitor visas, international postdoctoral scholars may not be aware of the differences in the purpose, eligibility, and requirements of these visas (Cantwell 2011). For instance, H1-B visas can be renewed and may lead to a green card, but individuals working under a J1 visa must return to their home country for at least two years before applying for a green card or re-entry. The complexity of the visa process is quite significant and could have consequences on a future career in the US (Ukachukwu et al. 2022).

While navigating US immigration policies and work visas is a considerable challenge, transitioning into the workplace can be even more difficult. International postdoctoral scholars report the highest rates of harassment of any postdoctoral scholars in the labor force (Woolston 2020). This discrimination frequently results in these individuals being placed at lower tiers of the academic labor force, limiting their ability to successfully transition to faculty positions (Lee 2013). Additionally, they report experiencing stigmatization, microaggressions, institutional barriers, lack of mentors, and negative messaging about their abilities (Karalis Noel et al. 2022).

International postdoctoral scholars also report a lack of transitional support, which diminishes their professional and career success. One central area of need is to further develop their academic English skills in oral and written communication (Ferguson et al. 2017). This is not surprising, as most postdoctoral scholars identify the need for more support in writing grants, journal articles, and technical reports (Nowell et al. 2020). International postdoctoral scholars also express difficulties in finding a supportive disciplinary and peer community in which they feel they belong (Karalis Noel et al. 2022). These feelings are worsened by unresponsive supervisors with misaligned work expectations and differential treatment of international and domestic postdoctoral scholars (Karalis Noel et al. 2022).

While international postdoctoral scholars face work-related difficulties in the US, institutionalized resources are in place to offset their challenges. For instance, most US colleges and universities have an international office to provide visa assistance, English language classes, and academic and career support (Ferguson et al. 2017). However, it is argued these support structures are woefully lacking, and more help is needed in navigating US immigration policies, filing US taxes, accessing healthcare benefits, improving English communication skills, and career networking (Gunapala 2014). Organizations such as the National Postdoctoral Association (NPA) provide postdoctoral advocacy seminars, collaboration and leadership opportunities, and career planning assistance to address these gaps. Although these resources are beneficial, few international postdoctoral scholars are familiar with or take advantage of them (Ferguson et al. 2017), despite researchers finding they are more likely to attend professional development and networking opportunities than their US peers (Nowell et al. 2020). Thus, a deeper understanding of their challenges and ways to ease them is needed to better support international postdoctoral scholars in the US.

2 METHODOLOGY

2.1 Research Design

An intrinsic case study (Stake 1995) was utilized to explore the challenges shared by international engineering postdoctoral scholars about working in the US. Intrinsic case studies are valuable when seeking to provide insight into a particular issue in which the case is secondary. Interviews conducted with eight international STEM postdoctoral scholars were analyzed inductively (Silverman 2019). The research question that guided this study was: What challenges do international engineering postdoctoral scholars experience in the US?

2.2 Participants

Fifty STEM postdoctoral scholars were recruited from the NPA via an email alert, although this inquiry analyzed the interviews of only the international engineering postdoctoral scholars. Participation was incentivized with a $25 e-gift card. The sample comprised a diverse group of engineers; three self-identified as female and five as male, and the ages of the participants ranged between 34 to 46 years. The postdoctoral scholars were from Canada, China, Colombia, Iran, Italy, and Thailand. Specific sub-engineering disciplines are not included to aid in masking participants' identities. A summary of participant demographics is listed in Table 1.

Table 1. Participant Demographics

Pseudonym	Gender	Age	Home Country
Abeo	Male	36	Canada
Angela	Female	35	Colombia
Armando	Male	46	Colombia
Camila	Female	43	Italy
Eugene	Male	44	Colombia
Jade	Female	36	Thailand
Jian	Male	34	China
Naadir	Male	39	Iran

2.3 Data Collection

Following Institutional Review Board approval, all participants were provided with a consent form detailing the purpose of the study, survey and interview procedures, and safeguards in place to protect their privacy and confidentiality. Before the interviews commenced, participants completed an online, open-ended survey gathering demographic information. A semi-structured interview protocol was created to examine participants' academic and personal backgrounds, their postdoctoral appointment's positive and negative aspects, and their process in identifying career goals. Open-ended probing questions were included for the researchers to seek clarification and meaning during the interview. Interviews averaged 60 minutes in length. All participants were given pseudonyms, and only de-identified interview transcripts were stored.

2.4 Reflexivity and Positionality

Throughout the study, the research team engaged in individual and collective reflexivity by reflecting upon, bracketing out, and dialoguing about experiences and beliefs concerning the challenges faced by international postdoctoral scholars in the US. In qualitative research, reflexivity is a crucial component of inquiry, positioning researchers to consider their bias and its potential impact on meaning-making and interpretations during data analysis. Additionally, researchers must disclose their positionality so readers know the unique perspectives they bring to the study (Lincoln and Guba 1985). The research team comprised social science American women trained in qualitative research methods within educational settings. Two are professors, and the other is a doctoral student. All are engaged in STEM education research, particularly in efforts to diversify the engineering professoriate and broaden success in STEM academia. This work is seen as a matter of social justice; therefore, empathy and humility were integral to the data collection and analysis processes.

2.5 Data Analysis

Inductive thematic content analysis techniques (Silverman 2019) were employed to explore the challenges shared by international engineering postdoctoral scholars about working in the US. The transcripts were coded individually through three review rounds, leading to 18 unique codes. Next, the researchers collectively cross-referenced the codes and identified five initial themes through consensus. Following consensus-building, the themes were refined for parsimony and to ensure the themes captured the entirety of the data and could be applied broadly. This refinement led to four final themes: (1) Immigration concerns; (2) Strains to find a community; (3) Pressure to publish and secure funding; and (4) Inadequate career counseling. This method allowed for flexibility and a successively deeper understanding of the challenges shared by the participants, which is valuable when approaching research patterns in inductive ways.

2.6 Trustworthiness

Multiple verification strategies ensured the findings were trustworthy by attending to credibility, transferability, dependability, and confirmability (Lincoln and Guba 1985). Researchers utilized cross-case synthesis to address credibility, assessing whether themes were similar or different among the participants' perspectives. Thick, rich descriptions with participant quotes aided in the transferability of the findings. The researchers' reflexivity and statement of positionality bolstered the dependability of the findings by providing transparency about their backgrounds and experiences on this topic. Confirmability of the findings and conclusions was made possible by involving multiple researchers in using the inductive thematic content analysis approach and by providing several feedback loops to validate the themes.

2.7 Limitations

As in all research inquiries, this study has several limitations. First, the researchers did not conduct member checks because arranging and conducting interviews was difficult due to participants' demanding schedules. Member checking might have provided more complex and nuanced depictions of their challenges. While the study attended to researcher bias through reflexivity and positionality, its potential to influence the findings and interpretations cannot be guaranteed. Last, this inquiry is primarily approached from an outsider's vantage point, as none hold an international or STEM academic background.

3 FINDINGS

3.1 Immigration Concerns

Nearly all participants indicated studying and/or working in the US was a lifelong goal. For instance, Naadir noted, "The best schools in environmental engineering are in the US based on global ranking of universities, so I knew I wanted to get my advanced training here." While none of the postdoctoral scholars shared difficulty in receiving their work visa, many noted visa restrictions and their plan to gain US residency status. Armando remarked, "Working here can be a little tricky for international people. I was working for a national lab, but I had some restrictions… I'm working on gaining residency, but if that doesn't happen, I'll have to go back home." Similarly, Eugene shared, "I need to change my residency status because I really want to spark the possibility of finding a permanent position in the US." US politics around immigration policies was noted by Angela, who stated, “Being a postdoc who’s also international during the Trump administration…there’s just like a ton of stress that when you look at the news, and there’s an immigration headline, and then you have no idea if it applies to you or not.” As the participants were planning for their futures, navigating US immigration and residency policies was met with much trepidation as they shared concerns about the length of the process and the uncertainty of the results.

3.2 Strains to Find a Community

Half of the participants discussed the difficulty in finding a community of postdoctoral scholars on their campus with whom to build friendships and support structures. Angela noted, “It’s just really hard to meet other postdocs, and I feel like there are things the institution could do to make that easier…I always say being a postdoc, it’s kind of isolating.” Abeo also discussed the isolation of the postdoctoral role, particularly in comparison to graduate school: “One of the main things that’s become really apparent is that it’s also a much more isolated experience than in grad school …part of what I liked about grad school was…there were a lot of people and things were happening, I felt more connected on campus.” Jian shared how she sought out her own connections: “I found a support group organization and another within the College of Engineering…I wish there was an orientation connecting these things and making it easier to access some of the supports for postdocs.” This desire to find a community was palpable for those who were single, while individuals with families did not share this as a central challenge.

3.3 Pressure to Publish and Secure Funding

All participants intimated being under tremendous pressure to publish and secure funding during their postdoctoral appointment. They indicated this pressure came from their postdoctoral advisors. However, they also understood these activities were important to master if they intended to move into a faculty role, particularly in the US. Angela commented, “This pressure to work all the time…there’s so much pressure to publish and to raise funds.” Moreover, while the pressure was high, many shared they had not received the direct instruction they hoped for. Abeo noted, “I’d sort of written scholarship and fellowship applications, but in writing bigger grants, I felt like I wasn’t particularly prepared for that after grad school. I was hoping that the postdoc would help with that.” Likewise, Jian shared, “It would be nice to know about professional events. I would like more support and training on how to get funding…I need more support in grant writing and grant applications in my postdoc.” Interestingly, Jade was the only one to mention the importance of finding a balance amid all the pressure: “It’s necessary to find a balance because you don't want to kill yourself, or lose your life, to be really productive in writing.”

3.4 Inadequate Career Counseling

All participants shared that little to no career counseling occurred with their postdoctoral advisors, but some indicated they had participated in institutional-sponsored career development activities. Jade said, “There's this type of confusion that I have these days on what I'm going to do next. I want to go into the professorship at a good university, should I do that here or go back to my home country? I need some more direction, but I'm not sure where I should get that from." Those focused on securing a faculty position mainly worried about their lack of teaching experience, as most had no teaching component connected to their postdoctoral work. Naadir stated, "I haven't had the chance to be a teaching assistant because here the teaching load is really light, and we don't have an undergrad program here." Others were interested in exploring research and industry positions but were unsure about how to find assistance in that area. Camila noted, "I wonder about a research position…I don't know much about them…I definitely need to think more about my next career step…I haven't had too many conversations about that." Abeo also expressed concern about inadequate career counseling: "If there were more resources for postdocs, especially more active career planning, that would be helpful…there might be jobs and situations that I don't necessarily know exist or have as much clarity of what it is they do." Clearly, additional support structures in this vein are warranted.

4 DISCUSSION AND CONCLUSION

4.1 Discussion

The purpose of this intrinsic case study was to explore the challenges faced by international engineering postdoctoral scholars working in the US. The inductive data analysis revealed four main themes: immigration concerns, strains to find a community, pressure to publish and secure funding, and inadequate career counseling. These findings confirmed and expanded upon the sparse literature on this topic. Notably, nearly all participants shared concerns about their immigration status and the hurdles they would need to overcome in order to stay in the US permanently. The strain in finding a postdoctoral community also is mirrored in the literature. All intimated intense "pressure to produce" publications and grant awards, coupled with a desire for greater support in these areas, as found by other researchers. Moreover, inadequate career counseling was discussed by all participants and was particularly acute for those who were deviating from initial plans to enter the tenure-track faculty job market, a topic all too familiar in the literature.

4.2 Implications

Implications abound for Ph.D. advisors outside the US whose students may pursue postdoctoral positions in the US, as well as Ph.D. recipients themselves. Awareness of common challenges faced by international postdoctoral scholars can aid in being prepared early. For instance, international postdoctoral scholars may want to pursue and advocate for an H1-B visa since it involves fewer restrictions than a J1 visa. Seeking a community of postdoctoral peers and fellow nationals before arriving in the US may prevent feelings of isolation. Also, the writing demands and inadequate career counseling may be alleviated through accessing professional development opportunities offered at the postdoctoral institution and by organizations such as the NPA. Likewise, US postdoctoral advisors and US institutional international offices must respond to these challenges in a systemic manner. Requiring postdoctoral advisor training and instituting individualized development plans that speak to personal and professional goals may ease the challenges identified. More work is needed at the institutional level to ensure international postdoctoral scholars thrive and are well-positioned to move forward successfully into academia or industry in their home country, the US, or beyond.

4.3 Future Research

Future exploration is warranted to understand whether these challenges are unique to engineering postdoctoral scholars or indicative of larger postdoctoral training trends that must be dismantled. In order to do so, additional interviews and a survey could be administered to broaden and strengthen the findings and implications of this study. Also, while challenges with microaggressions did not rise to the level of a main theme, one postdoctoral scholar of Nigerian descent shared two related experiences. One interaction was with lab mates where it was suggested that it was easier for Black students to earn scholarships and fellowships in the US suggesting their skin color rather than merit dictated these accolades. Another was a one-on-one conversation in which he was told the academic bar was lower for women in the US. In both instances, the postdoctoral scholar was stunned and unable to respond, as he had little experience with racially- and gender-charged exchanges in his home country. Future research into this area could be informative and shed light on the comparable and divergent experiences of US Black, Latinx, Indigenous, Asian, Pacific Islander, and White women who also are subjected to these types of microaggressions.

4.4 Conclusion

This intrinsic case study provides a deeper understanding of the challenges faced by international engineering postdoctoral scholars and ways to ease their challenges and aid in their career success. The findings indicate four major challenges: immigration concerns, strains to find a community, pressure to publish and secure funding, and inadequate career counseling. Raising consciousness on these challenges and ways to ease them is critical to postdoctoral success and the growing international postdoctoral US labor force.

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REVOLUTIONISING ENGINEERING EDUCATION: CREATING PHOTOREALISTIC VIRTUAL HUMAN LECTURERS USING ARTIFICIAL INTELLIGENCE AND COMPUTER GENERATED IMAGES

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Keywords: *photorealistic, embodied virtual agents, artificial intelligence, computer generated images, education*

ABSTRACT

The COVID-19 pandemic has disrupted traditional classroom learning, making virtual and remote education increasingly important. In this context, the use of photorealistic virtual humans, or avatars, powered by Artificial Intelligence (AI) can offer an immersive and engaging environment for delivering traditional classroom-based lectures. This paper proposes a process that combines AI and Computer-Generated Images (CGI) to create photorealistic virtual human lecturers for educational purposes.

The proposed process flow involves generating audio from text inputs, which is passed to a 3-Dimensional (3D) facial animation rig that matches lip, tongue, eye and facial movements to the audio using AI. This generates a base mesh for speech animation which is refined using morph targets and blend shapes, resulting in a highly realistic facial animation. Game engines and photogrammetry is used to generate a photo-realistic human avatar, to which the base mesh is mapped to generate a photorealistic animated avatar.

Virtual humans offer several advantages over real persons, including the ability to customise the persons appearance, voice, accent, language, location, mannerisms etc., making them an ideal solution for global education.

The process flow will describe the methods, analysis and interpretations for using AI to generate natural photo-realistic avatars, and the potential contributions to the advancements in engineering education.

In conclusion, virtual humans have the potential to revolutionise the way education is delivered in a post-COVID world. By combining AI and CGI, photorealistic virtual human avatars can be created that are highly engaging, customisable, and accessible to students all over the world.

1 INTRODUCTION

This systematic review examines previous research conducted on the use of Embodied Virtual Agent (EVA) as lecturers in higher education. The aim is to provide a comprehensive analysis of the effectiveness, advantages, and limitations of utilising these EVAs in higher educational settings – both from a student and lecturer perspective, in particular, how do lecturers perceive and respond to EVAs?. It highlights the intention of the Rethinking Engineering Education in Ireland (REEdI) project to explore the development and integration of EVAs using Artificial Intelligence (AI) and immersive or Extended Reality (XR) - which includes Augmented Reality (AR) and Virtual Reality (VR) - into Science, Technology, Engineering and Mathematics (STEM) programmes Munster Technological University (MTU), Kerry Campus. REEdI combines an innovative method of content delivery with XR to deliver a truly transformative programme to deliver fully remote, immersive, and collaborative solutions to engineering students and lecturers. Students will utilise XR as a point-of-contact with lecturers while on extensive work placement, which will extend the duration of 2 years at geographically dispersed locations. Students, lecturers, and mentors can meet virtually and collaboratively regardless of their geographical location in real-time to discuss progress and to collaborate on engineering challenges; or interact with proposed pre-created content such as lecturing sessions using EVAs.

The objective is to augment the proficiencies of engineering students and in higher educational settings and within industry. It is crucial to emphasise that the implementation of these technologies is not intended to supplant lecturers, but to supplement and empower them in their instructional roles.

2 METHODOLOGY

2.1 Identification and search strategy

Searches were conducted in the following databases: IEEE Explore, JSTOR, PubMed, Springer Link, and Taylor & Francis Online. Searches were aimed at articles published between January 2010 - 2023. Search terms included "*embodied virtual agents*", "*virtual reality*", "*virtual instructors*", "*engineering education*", "*higher education*", “*photorealistic*”, and “*artificial intelligence*”. Search terms were combined using Boolean operators AND, OR to expand/narrow the search. Figure 1 illustrates the total number of publications as inclusion/exclusion criteria were applied.

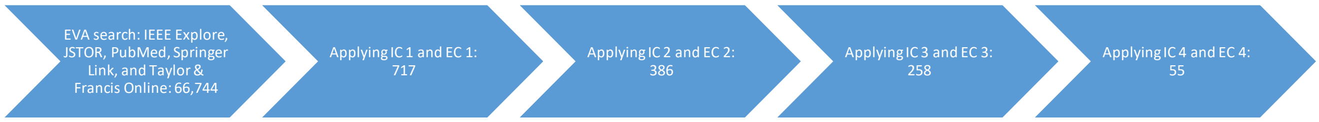

Fig. 1. Flowchart of Identification and Search strategy

Of 55 publications, 20 were identified through the inclusion/exclusion criteria highlighted in *Section 2.2, Table 1*, with 2 publications dated pre-2010 included (Maldonado and Nass 2007) (Slater 2003). These publications emphasised the presence and emotional aspects, which do not directly mirror the technological progress during the time of publication or currently. Figure 2 illustrates the publications timelines including publication methods.

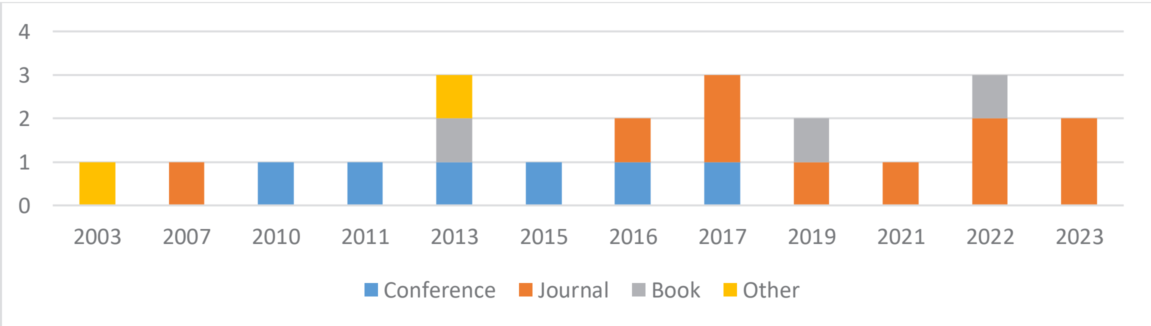

Fig. 2. Publication timelines

2.2 Inclusion and exclusion criteria

The term "*embodies virtual agent*" was used as the primary search criteria. Additional considerations and inclusions applied to studies focused on on-the-job skills-training where relating to XR (Batrinca, et al. 2013) (Gratch, DeVault and Lucas 2016) (Suárez, Jung and Lindeman 2021). Studies that focused on primary and secondary school education, duplicate studies with similar content, non-peer-reviewed sources, or articles not available in English were excluded from the review.

Table 1. Inclusion and Exclusion criteria

Inclusion Criteria: IC	Exclusion Criteria: EC
IC 1: Relevance to XR	EC 1: Not in English or open access
IC 2: Focusing on higher education	EC 2: Primary or secondary schools
IC 3: Focusing on engineering	EC 3: Duplicate studies
IC 4: Using EVAs as lecturers	EC 4: Not using AI

2.3 Study selection

Studies were selected on their relevance to education, and in particular to engineering education, as well as its relevance to using XR as a delivery method. In the case of VR, care was taken on the type of VR, focusing on Head Mounted Displays (HMDs) as opposed to screen-based VR solutions.

2.4 Data extraction

The following data points were extracted from the selected publications: (1) study characteristics, (2) sample characteristics, (3) educational context, (4) virtual agent features, and (5) key findings. The most noteworthy key findings were from Swartout et. al. (Swartout, et al. 2013). The authors demonstrated that individuals interacting with virtual humans: (1) exhibit responses akin to those elicited by real individuals, (2) display enthusiasm towards engaging with these characters, and (3) acquire knowledge and information through the communication conveyed by these characters. The use of VR in education has proven pedagogical advantages such as enhancing learning outcomes, and increased engagement, motivation, and involvement (Boyle, et al. 2022) (Fitton and Finnegan 2022).

3 RESULTS AND FINDINGS

3.1 Exploring the potential of EVAs: enhancing engagement, emotion and empathy

The use of XR in education have garnered interest and widespread implementation in recent years, while the COVID-19 pandemic prompted educational institutions worldwide to adapt to remote learning methodologies. Conversational voice assistants like Apple's Siri or Amazon's Alexa may be impressive but lack the capability of conveying emotion and empathy. This limitation lies in their lack of physical presence and visual representation.

The most extensively used XR applications revolve around training simulations for e.g., pilots, machine operators, hazardous occupations like mine workers, military personnel, and medical staff. (Boyle, et al. 2022). These applications focus on hands-on training, and typically lack virtual instructor guidance, instead relying on audio prompts and/or text instructions.

Provoost et.al. (Provoost, et al. 2017) defines EVAs as computer-generated avatars designed to replicate essential facets of interpersonal communication, encompassing both verbal and nonverbal cues. Guetterman et. al. (Guetterman, et al. 2017) describes agents that are programmed and controlled by computer algorithms, with the ability to interact with real people using verbal and non-verbal behaviours. EVAs can simulate human-like behaviours, expressions, and gestures, fostering a sense of connection and creating a conducive environment for meaningful interactions (Slater 2003). For EVAs to be successful, it is necessary for users to perceive and respond to them socially in a realistic way to elicit the feeling of presence (Kyrlitsias and Michael-Grigoriou 2022). Presence is intertwined with immersion (Slater 2003), and is influenced by attributes of the VR system and the level of immersion (Ijsselsteijn and Riva 2003). Endeavours in the field of VR have predominantly focused on presence, given its correlation with the efficacy of VR experiences. The degree to which users perceive themselves to be present within the virtual environment directly impacts the realism of their reactions and behaviours, thereby contributing to the overall success (Cummings and Bailenson 2016). Fitton et al. (Fitton and Finnegan 2022) report on the influence of an EVA and students' perception of presence on various aspects of learning including retention, satisfaction, engagement, and motivation. The study highlights the potential for EVAs to overcome limitations associated with lecturer-student ratios and classroom size. IVEs possess the capability to enhance the perception of interpersonal connectedness, enabling EVAs to evoke emotions associated with social presence (Suárez, Jung and Lindeman 2021).

3.2 Assessing the effectiveness of EVAs in higher education and remote learning environments: knowledge transfer, retention and comprehension

The role of EVAs as a teaching aid, and its integration into formal education settings is relatively infrequent. One of the most popular utilisations focus on the use of pre-recorded videos in Massive Open Online Courses (MOOCs). MOOCs encompass a video-recorded presentation by a lecturer, enabling students to fulfil assignments, and engage in scholarly discourse through online forums (Feng, et al. 2015). Despite their potential, they face challenges such as learner attrition and motivational factors (Yang, et al. 2013), and significant resource requirements from lecturers for lesson recording, and post-production editing. It can be contended that delivering lessons through platforms like Microsoft Teams (Microsoft 2023) or Zoom (ZOOM 2023) entails a lower resource burden per session. EVAs enhance the credibility and relatability of the virtual agents, making them more effective in delivering complex educational content such as engineering principles (Fitton and Finnegan 2022).

The utilisation of EVAs holds significant importance for effective pedagogy (Soliman and Guetl 2010). Prior scholarly indicate that the portrayal of artificial agents influences learners' motivation (Maldonado and Nass 2007). Learners have the option to personalise EVAs according to their preferences, and such customisation has demonstrated enhanced performance in certain cognitive tasks (Lin, et al. 2017), and it was observed that the female pedagogical agent was generally favoured (Novick, et al. 2019).

Swartout et al. (Swartout, et al. 2013) report on a system known as the Twins (Ada and Grace), who serve as virtual characters within the Cahners Computer Place at the Museum of Science, Boston, and are envisioned to possess autonomous capabilities such as independent thought processes, emulating and expressing emotions, and engaging in seamless and organic interactions through verbal and nonverbal means. The primary objective is to achieve a high level of authenticity in their appearance, communication, and behaviour, aiming to closely resemble real individuals (Swartout, et al. 2013). Functioning as digital docents and STEM role models, they engage with visitors by providing information on the exhibits and activities and responding to general inquiries. The Twins are designed to possess embodied social characteristics, exemplifying traits such as sibling rivalry through their banter, actively engaging in conversations, disclosing details about their personal backgrounds, preferences, and even relationships. This deliberate design approach aims to establish a relatable and captivating experience (Swartout, et al. 2013). The utilisation of conversational interaction enables the establishment of rapport, fostering trust, and motivation, and evaluations of these systems demonstrate that individuals interacting with virtual humans (1) exhibit responses akin to those of real individuals, (2) display enthusiasm towards engaging with these characters, and (3) acquire knowledge and information through the communication conveyed by these characters.(Swartout, et al. 2013). EVAs exhibit significant utility across diverse domains, encompassing cognitive-science investigations, training methodologies, educational practices, and recreational applications. (Campbell, et al. 2011). Recent advancements in AI, in particular Large Language Models (LLM), such as ChatGPT (OpenAI 2023) and computational processing power, allow for EVAs to be programmed with interactive capabilities to respond to students' queries, provide feedback, and engage in interactive conversations in real-time.

3.3 Potential benefits and drawbacks of EVAs in education

XR in education has numerous pedagogical advantages such as enhancing learning outcomes, increasing learner's motivation and involvement, engage in experiential learning, and facilitating deeper levels of understanding and cognition (Boyle, et al. 2022). By enabling learners to actively explore and interact with virtual objects and events, VR transcends the passive modes of observation and listening typically associated with traditional learning approaches (Boyle, et al. 2022). Additional advantages include reduced travel time and the impact it has on the environment, cost, and requirements for physical space. To realise their full advantage, it is crucial for EVAs to augment and supplement the role of a lecturer. Table 2 shows potential benefits and drawback of EVAs in higher education.

Table 2. Advantages and drawbacks of using EVAs in higher education.

Advantages	Drawbacks
Improved learning outcomes such as increased retention and improved knowledge application.	Requirements for sophisticated AI algorithms and computational resources
Can become part of the content through posture, clothing e.g. safety gear, expression, etc.	Ensuring ethical use of data and privacy protection.
Customisable attributes such as appearance, voice, accent, language, location, and mannerisms.	Concerns related to the impersonal nature of EVAs compared to human lecturers.
Accessibility and inclusivity through gender, ethnicities, or physical abilities.	
A sense of novelty and excitement which increases motivation and engagement.	
Resource savings such as travel time, cost and impact on environment	

3.4 Utilising AI and CGI for EVA generation: Understanding the technology behind photorealistic EVAs in education and overcoming technological barriers

EVA creation is becoming less resource intensive with the advancements in more sophisticated and accessible computer hardware and software. For the creation of the EVAs, this systematic review proposes the following combination of technologies: Play.ht (Play.ht 2023), NVidia Audio2Face (NVidia 2023), and Unreal Engine METAHuman (Engine 2023). The proposed process flow for the REEdI programme is described as follows: Using text and lecture material, the REEdI lecturer generates an audio file by passing in text cues. This can be enhanced by uploading a base sample of the lecturers' own voice, which can then be replicated using AI. Using the audio file, NVidia Audio2Face is used to synch the audio to a generic facial mesh rig that will mimic the audio using AI. The AI manipulates the face, eyes, mouth, tongue, and head motion to match a selected emotional range, or automatically infers emotion directly from the audio clip. METAHuman. Depending on the level of complexity required, the lecturer can choose from: (1) a premade facial template, (2) generic fictional character, or (3) scan their own features that maps and recreates their facial features to the base METAHuman. The last technique yields a photorealistic mesh of the lecturer. The total creation time requires less than 90 minutes to produce a photorealistic EVA that is fully rigged and operational. The EVA creation process, including proposed output, is shown at a high level in Figure 3.

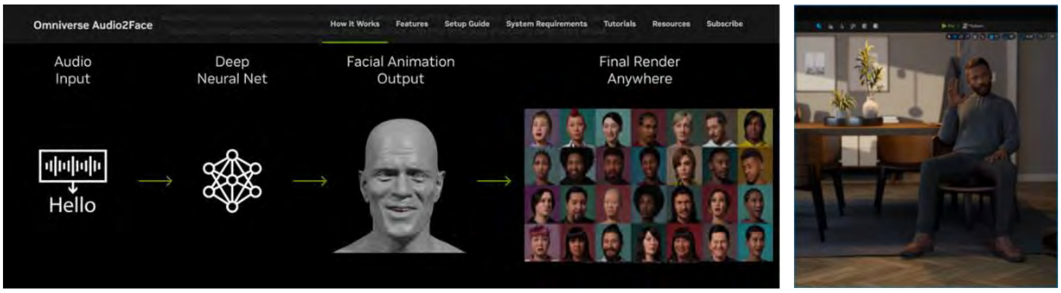

Fig. 3. EVA creation process flow (left) and proposed output (right).

4 DISCUSSION

A systematic review focusing on EVAs highlight the existence of positive outcomes such as improved learning outcomes and engagement, and enhanced student satisfaction, yet there remains gaps in the analysis that correlate directly to the benefits attributed to lecturers such as 1-to-1 interactions in large class sizes, optimal use of finite resources such as physical spaces, and diverse student needs e.g., language and disabilities. There are several limitations and challenges that need to be addressed, for instance, creating the framework on which EVAs are built is technically challenging and requires specialised skillsets such as software development which could be a potential barrier for many. The training needed by lecturer, coupled with time and resource constraints could potentially be another barrier. Further limitations relate to the existing research (small sample sizes) and lack of long-term studies due to the nature of this new cutting-edge technologies.

Potential areas for future investigation are discussed below in the form of research questions. Based on this systematic review, practical recommendations for educators, institutions, and policymakers interested in implementing EVAs as lecturers include the need for innovation, alignment with industry needs, and the importance of professional development for educators.

5 CONCLUSION AND FUTURE RESEARCH

This systematic review explored the potential of using EVAs and their contributions to the advancement of education. The methods, analysis, and interpretations presented herein demonstrate how EVAs can enhance the delivery of teaching concepts and foster a deeper understanding among students. The immersive and interactive nature of EVAs can effectively simulate real-world scenarios, enabling students to engage in experiential learning and problem-solving exercises. EVAs can be a valuable component of eLearning, but their effectiveness depends on their implementation. When they are designed poorly, they can add to the extraneous information and impede the learning process. However, when they are created with a high level of realism, they can enhance retention and facilitate the application of knowledge in real-world situations.

As highlighted in the research, the implementation and integration of EVAs into higher education is relatively infrequent. Based on this and the limitations identified in previous literature reviews, this systematic review formulated the following research questions aimed at engineering education in HEI environments using EVAs to augment student and lecturer pedagogies using XR technologies: (1) How do lecturers perceive and respond to EVAs?, (2) How do students' perceptions of the social presence and instructor support in VR-based engineering education compare to traditional classroom settings?, (3) How do students' learning preferences and attitudes towards technology influence their acceptance and adoption of EVAs and VR technologies in engineering education?, (4) What are the key design principles and considerations for creating effective EVAs for engineering education in VR?, (5) What are the best practices for integrating EVAs and VR technologies into the existing curriculum of higher education engineering programs?, (6) What is the effectiveness of AI controlled photorealistic EVAs as lecturers in engineering education?

The first question draws correlation to engineering education specifically, while the second and third questions focus on the technical design and implementation of EVAs for VR in higher education. The final 3 questions seek to explore the reciprocal interaction between students and AI controlled EVAs, and the subsequent advantages and/or drawbacks this may reveal.

The REEdI project aims to incorporate EVAs into the existing Bachelor of Engineering (Honours) Degree in Mechanical and Manufacturing Engineering to bolster and complement the instructional efforts of lecturers by leveraging XR technologies, thereby optimising the educational outcomes for students.

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STUDY SUCCESS AND FAILURE OF STEM STUDENTS AND THE CONNECTION TO THEIR LEARNING HABITS

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ABSTRACT

With the educational expansion, ever more students start a tertiary degree. At the École Polytechnique Fédérale de Lausanne, an engineering school, the number of bachelor students increased from 3’713 in 2010 to 6’330 in 2022. However, in Switzerland, a considerable number of students fail to achieve their first university degree – and failure rates are even higher at engineering schools. A weak mathematics background is often identified as the main reason for dropout. In this paper, we are interested to test whether inadequate learning habits are also responsible to some extent for first-year dropouts. To this end, we matched admission data with self-assessed data about learning habits. These learning habits include time management, effort regulation, and the learning strategies of elaboration and organization ($204 \leq N \leq 823$). These scales are based on one of the most often used instruments for self-regulated learning, the Motivated Strategies for Learning Questionnaire, and have been shown to correlate with academic success in various fields (Credé and Phillips 2011).

Using logistic regressions, we find that time management and elaboration are correlated with higher probabilities of study success. Furthermore, higher scores in all learning habits but organization are related to a lower probability to repeat the first year of a bachelor's degree. Thus, together with better math skills, learning habits contribute to more and faster success in STEM fields and thus to higher student retention.

1 INTRODUCTION

The educational expansion that started in the 20th century is still ongoing today, leading to more tertiary education students. Concretely, at our local engineering school, the École Polytechnique Fédérale de Lausanne (EPFL), the number of bachelor students increased from 3’713 in 2010 to 6’330 in 2022. However, access to tertiary education doesn’t equal success, as many students fail to achieve their bachelor’s degree (Bernardo et al. 2021). Contrary to other countries, where access to engineering schools is based on an admission exam, in Switzerland, access is granted to any Swiss student with a high school diploma. Therefore, at EPFL, the failure rate for the first year is close to 35%, and of the successive sample only around 70% of the students succeed the first year on the first attempt. Weak background in mathematics is often identified as an important factor for dropouts in engineering. However, in this study, we are interested to test whether inadequate learning habits are also responsible to some extent for first-year dropouts. Researchers at EPFL have developed a tool that assesses students’ learning strategies and gives feedback thereupon to support students in their learning. As one of the first steps in validating this tool, we analyze whether the assessed learning habits relate to study success and failure measures.

1.1 Why university dropout matters: Preventing personal and societal costs

One of the oldest claims of why reducing dropout rates matters, especially in STEM fields, exists at least since the end of the Second World War (Smith and White 2019): As it goes, there is not enough supply of highly skilled STEM people for an innovative, growing economy or for basic research. However, Charette (2013) shows that even though there are a prognosticated 277’000 STEM vacancies per year in the United States, there are also more than eleven million people with a STEM degree in the US working outside of STEM, and more than half of the people working in STEM do not hold (and probably not need) a corresponding tertiary degree. Similarly, for the UK context, Xue and Larson’s (2015) analysis of the STEM labor market paints a heterogeneous picture, with shortages e.g. in software development and data science, and surpluses, especially in the academic sector.

Thus, the STEM crisis argument only holds partially, and from other perspectives, dropout might even be desirable. From a practical perspective, there might not be enough space to accommodate all students or over-enrolment might lead to a student-teacher imbalance and, hence, bad student support service. From an elitist perspective, one can assume that good higher education institutions in Europe are characterized specifically by a higher failure rate – as a valuable good, i.e., a degree from a prestigious university, is a sparse good. While these arguments can be contested (e.g., remote teaching in case of space problems; training more teacher assistants for student support), a more severe problem comes from a macro-sociological functionalist perspective: the claim of grade and degree inflation. That is if ever more students are admitted to a tertiary degree and all would graduate (with higher grades), then a university degree loses its information for allocating human resources adequately in the labor market, which is a central function of the educational system. However, supporting students also has clear societal and personal benefits. The education of students who finish their studies faster costs the taxpayer less than when students start several studies without finishing. Also, students who graduate will earn more and consequently pay more taxes, and need fewer welfare subsidies. From a personal development perspective, two issues need to be mentioned. First, many mental disorders emerge in the mid-20s (Kessler et al. 2007). Next to being a driver for school or university dropouts, mental disorders might also be reinforced through dropouts (Ramsdal, Bergvik, and Wynn 2018). Dropouts might be reduced by adequate social support or induced social gatherings that spark peer support (cf. Stadtfeld et al. 2019). Second, and to counter the argument of degree inflation, retention should always go hand in hand with fulfilling academic skills requirements. Meta-analyses have shown that study skills relate to academic success and, importantly, that study skills can be taught (Jansen et al. 2019). Thus, a better understanding of which study skills are most predictive of dropout in STEM studies might contribute to the design of a support program for struggling students so that the dropout rate can be reduced while the required academic level is still achieved.

1.2 Inadequate learning strategies as drivers of university dropouts

The underlying assumption of the Learning Companion, the tool developed by researchers from EPFL, is that first-year students need to adapt from learning at high school to learning at the university level (Tormey et al. 2020). In high school, students are used to solving routine problems, where they might shortly scan the problem and then try to apply a predefined method. At the university level, they often face problems that they must first analyze, and design a suitable method for effective problem-solving. This problem-solving process requires increased metacognitive skills like planning, monitoring progress, and regulating learning strategies. Thus, students are often ill-equipped when entering university, and teaching them the right learning strategies might help them complete their degree.

Research on self-regulated learning and learning strategies in tertiary education has been abundant, leading to meta-analyses with hundreds of studies (Jansen et al. 2019, Richardson et al. 2012). Nevertheless, the present study can contribute to existing research in two ways: First, studies on self-regulated learning in STEM courses, explicitly, are rare (see Jansen et al. 2019). Second, the dependent variables in studies on self-regulated learning are generally either performance in course exams or grade point averages, but not failure/dropout and success in a tertiary degree (though, there is a new research branch on dropout in massive open online courses).

Regarding study findings, one meta-analysis focusing on the Motivated Strategies for Learning Questionnaire (MSLQ) shows that general skills such as time management, effort regulation, and metacognitive self-regulation seem to be more important for academic performance than specific learning strategies such as rehearsal, critical thinking, elaboration, and organization (Credé and Phillips 2011). Thus, those three most effective learning strategies were chosen for analysis in this study. We also consider elaboration and organization because these are scales assumed to depict deep learning strategies (McKenzie, Gow, and Schweitzer 2004) and are necessary for self-regulated problem-solving which is crucial for success in traditional STEM courses. Credé and Phillips (2011) argue that specific learning strategies might play a different role for weak and strong students and might not have a linear relationship with academic performance. Thus, it merits investigating the relationship between study strategies and study success for weak and strong students separately.

This leads us to the following hypotheses: 1) Metacognitive self-regulation, time management, effort regulation, elaboration, and organization are facets of learning habits that help undergraduate students succeed in their first bachelor's year; 2) Higher scores on those learning habits shorten the time necessary to complete the first year; 3) Weak and strong students benefit differently from higher scores in learning habits.

2 METHODOLOGY

2.1 Data source, data collection, and sample description

Students from EPFL are sent letters during the summer break before their first semester and invited to fill out a self-assessment questionnaire about their learning habits. The goal is to give them feedback on how they fare in their learning habits and where they might improve to get through their studies. Scores on learning habits are extracted from the developed online tool, the Learning Companion. Additionally, data on gender, type of baccalaureate, registered inscriptions to courses, and national background were provided from study admission and merged with data on learning habits. In total, 1257 students filled out at least one scale on the Learning Companion. Exactly two third of the sample are men and one-third are women. Forty-nine percent of the sample went to high school in France and 22% completed high school in Switzerland with a focus on physics and applied mathematics. The rest did a Swiss baccalaureate with a focus on biology and chemistry (12%), an unspecified different focus (10%), or come from a foreign country other than France (7%).

2.2 Measures

Dependent variables. Success in the first bachelor's year and the duration to complete it is inferred from the data on registered inscriptions to courses. Data on inscriptions is provided on the level of the semester, thus, BA1 and BA2 designate the first year. After a failed first semester, some students take a course to improve their maths skills (in French called *mise-à-niveau*, MAN) before they try the first year again. Success in the first bachelor's year is assumed by reaching BA3, and study failure is assumed in case of discontinuation of inscription before BA3, that is, success in the first year can be achieved after MAN or other repetition, in which case the duration to complete the first year of study is longer than one year. Thus, the dependent variables are success/failure in the first year (coded as 1 = success and 0 = failure), and duration to complete (coded as 0 = two or fewer semesters needed to complete and 1 = needed more than two semesters to complete). Only students that did succeed in their first year are included in the analysis of the duration of it.

Independent variables. The type of baccalaureate was used to group students into students with weak and strong math backgrounds. Students who completed their baccalaureate in Switzerland in physics and applied mathematics as well as students from France (who had to pass a demanding admission test) were rated as having a strong math background. All other students were rated as having a weak math background.

The Learning Companion contains scales on study attitudes and habits and relies on existing questionnaires as well as on self-invented items. The analysis of this paper only includes learning habits scales borrowed from the MSLQ by Pintrich et al. (1991) translated into French. These scales are metacognitive self-regulation, elaboration, organization, effort regulation, and time and study environment. Every scale of the questionnaire can be filled out separately. Table 1 shows how many students participated in each scale. The construction of the scales has been criticized before (Credé and Phillips 2011). Therefore, we also allowed ourselves to make meaningful adjustments for one scale.

For instance, the original time and study environment scale from the MSLQ contains six items on time management and two on study environment but, it is unclear why study time and environment should form one factor. In our factor construction, we disregarded the two items of the study environment and called this factor time management (see a description of all scales in Table 1).

Table 1. Description of the MSLQ scales used

Scale	Nº items	Cronbach's α	n	Description of the scale and example items
Metacognitive self-regulation	12[1]	0.71[1]	727	Assesses metacognitive skills such as planning, monitoring, and regulation. Example item: When reading for this course, I make up questions to help focus my reading.
Time management	6	0.68	333	Assesses whether students make good use of study time, do assignments, attend classes. Example item: I find it hard to stick to a study schedule.
Effort regulation	4	0.68	333	Measures the ability to keep working even in case of boredom, distraction, or challenges. Example item: I work hard to do well in this class even if I don't like what we are doing.
Elaboration	6	0.68	204	Measures whether students connect different sources, use previous knowledge to situate new information, or apply new information to the real world. Example item: I try to understand the material in this class by making connections between the readings and the concepts from the lectures.
Organization	4	0.65	823	Measures whether students organize new information in schemes, diagrams, charts, or if they summarize important concepts. Example item: When I study for this course, I go over my class notes and make an outline of important concepts.

[1] The original scale consists of 12 items. However, after confirmatory factor analysis we excluded one item. Cronbach's α refers to the scale with the 11 remaining items.

2.3 Data analysis

We calculated the latent concepts separately for each study habit using confirmatory factor analysis (CFA). We obtained acceptable to good model fits for every scale. However, we had to exclude one item ("I often find that I have been reading for class but don't know what it was all about.") and correlate the error terms of four pairs of items for metacognitive self-regulation; we correlated the error terms of one pair of items for elaboration and organization and for two pairs of items for time management. To be able to compare the latent scores of the scales for students with weak and strong math backgrounds, we tested for and could approve scalar measurement invariance (MI, see table 2 for model fits). The CFAs with scalar MI constitute our final models and are used to predict the latent variable scores, which were then subsequently used for logistic regressions. Model fits are deemed good when satisfying the following values: p-value of χ^2 is >.05, robust CFI > .95, robust RMSEA < .06, SRMR < .08 (Hu and Bentler 1999).

Table 2. *Model fits of scalar measurement invariant CFA of the learning habits for the groups of students with strong and weak math backgrounds*

Scale	**n**	***df***	χ^2	***p***	**CFI**	**RMSEA**	**SRMR**
Metacognitive self-regulation	727	100	169.9	<.001	0.922	0.046	0.052
Time management	333	24	33.5	.093	0.958	0.055	0.052
Effort regulation	333	10	10.4	.407	0.998	0.017	0.035
Elaboration	204	26	15.1	.955	1.000	0.000	0.050
Organization[1]	823	7	7.1	.419	1.000	0.006	0.021

[1] reached partial scalar measurement invariance: intercept of one item was set to vary between the two groups. Note: multivariate distribution of the scales was non-normal, therefore, maximum likelihood estimation with robust standard errors and a Satorra-Bentler correction was used. We report robust values for CFI and RMSEA.

For both dependent variables, success/failure in the propaedeutics and duration of propaedeutics, we performed a series of logistic regression analyses with each learning habit separately. First, we tested a null model, then we introduced the learning habit to see if this has any predictive effect. Third, we introduced the group variable of weak and strong math backgrounds to see if those groups have significantly different probabilities to succeed or repeat. And fourth, we tested an interaction effect between the learning habit and the group to analyze whether the learning habits have different effects for the two groups regarding their probability to succeed or repeat during the propaedeutics. We run analyses of deviance to select the best-fitting model for each learning habit.

3 RESULTS

3.1 Success and duration of the first year

As mentioned in the introduction, the failure rate in the first year at EPFL is close to 35%. Some of those students drop out after their first semester. A second group of students drops out after the MAN semester, and a third group drops out after repeating the full first year of study. Once students make it to the second year, they hardly fail anymore.

Our analyses, presented in Table 3, show only partial support of hypothesis 1: time management and elaboration are significant factors for study success in the first bachelor's year, however, effort regulation, metacognitive self-regulation, and organization do not contribute toward a higher probability of success in the first year.

Table 3. Best-fitting logistic regressions

Learning habit	**DV**	**n**	$\beta_{learnstrat}$	$p_{learnstrat}$	β_{group}	p_{group}
Metacognitive self-regulation	Success	727	0.054	.102	0.137	<.001
	Duration	536	-0.157	.003	–	–
Time management	Success	333	0.077	.020	0.167	<.001
	Duration	248	-0.161	.001	–	–
Effort regulation	Success	333	0.026	.267	0.172	<.001
	Duration	248	-0.085	.011	–	–
Elaboration	Success	204	0.142	.003	–	–
	Duration	154	-0.282	<.001	–	–
Organization	Success	823	0.022	.130	0.187	<.001
	Duration	607	–	–	–	–

Note. DV = dependent variable; β_{group}: reference group is weak math background

Support for hypothesis 2 is present for all learning habits but organization: higher scores in learning habits generally shorten the time to completion of the first year. Finally, hypothesis 3 that learning habits affect academic performance differently for weak students than for strong students cannot be supported. The estimates for the interaction effects were all found to be non-significant. Table 2 shows that when controlling for the respective learning habits, students with a stronger math background have a higher probability of success than those with a weak math background (except for elaboration). Additionally, t-tests on the learning habits for the two groups indicate that students with a stronger math background score significantly higher – with the exception of organization (p = .203). Effect sizes of these significant differences in learning habit scores are small, ranging from Cohen's d = 0.24 for time management to 0.35 for elaboration.

3.2 Discussion

The analyses lend partial support to our hypotheses and are generally in line with existing research linking self-regulated learning with course performances or grade point averages. Success in the first year depends not only on inferred math background but also on time management skills and the learning strategy of elaboration. Regarding previous research, it is a bit surprising that effort regulation is not a significant contributor to study success, as this factor usually has one of the highest correlations with grades (Credé and Phillips 2011). Furthermore, higher scores in the measured learning habits are related to a shorter duration needed for completion – except for the learning strategy organization. This finding seems to indicate that training students to develop their learning habits is a good investment for universities to reduce the overall length of studies. In sum, we can assume that higher math and certain learning skills positively impact the probability of success. At EPFL, supporting students with their math skills is already institutionalized with the MAN semester offered to students who fail the first semester. However, student retention might be improved by providing more diverse or tailored study courses to struggling students, as 56% of the students taking a MAN semester are students with a strong math background, and still, only 31% of all those taking a MAN semester succeed in the end. It is also noteworthy that students with an assumed stronger math background generally score higher in those learning habits, and students with a strong math background and high scores in learning habits have especially high success probability. This indicates that a specially designed semester that should close the gap between failing and succeeding students should not only focus on math skills but also on learning habits. A book on "learning to study" (Tormey and Hardebolle 2017) and a MOOC were produced supporting the online self-assessment tool. However, we lack evidence on the adoption of those media by our students and further dissemination should be fostered. For example, during the MAN semester, some hours might be dedicated to developing impactful learning habits using those media.

This research also yields three limitations. First, the internal consistency of the scales is rather low for a commonly used instrument (MSLQ). Second, there seems to be a self-selection bias to fill out the questionnaire at least to some degree: more students succeed in the propaedeutics in our sample than of the full student population (78% vs. 66%), the percentage of students who did MAN in our sample is double as high as in the full student population (35% vs. 17%), and in the analyzed sample only 29% of the students are assumed to have a weak background in mathematics, while in the full population, it is 39% of the students. Third, the true relationship between the dependent and independent variables might be stronger than our results suggest, as study failure or success is a global measure, while the MSLQ measures are course specific (Credé and Phillips 2011).

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Can oral examinations replace written examinations ?

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ABSTRACT

The purpose of any assessment is to determine students' learning. While oral examinations have been adopted in many education systems, such as the PhD thesis viva and medical assessments (Huxham, Campbell, and Westwood 2012), they are rarely used in undergraduate engineering courses (Baghdadchi et al. 2022) which traditionally rely on written papers. This is not surprising given, generally, the large cohort sizes and the need to efficiently conduct such examinations in a timely manner. It has been shown that widening the range of assessments that a student experiences can lead to a more comprehensive development of the student (Rust 2005) and generally increases accessibility to the increasingly diverse student populations we find in engineering.

In this review, the effectiveness of oral exams is discussed and analysed in terms of their historical development, key features and differences from written exams and experience from case studies. The issues of validity, reliability, and fairness are outlined and the feasibility of replacing traditional written exams by oral exams in undergraduate programs, specifically the Mechanical Engineering program, at Imperial College London discussed.

It is recognised that while numerous benefits could be provided by oral exams there are significant hurdles that require careful planning and the review concludes with a number of guidelines for a pilot scheme to be enacted over the coming year.

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1 INTRODUCTION

1.1 History development

An oral examination, also known as viva voce is simply defined as "any assessment of student learning that is conducted by the spoken word", (Joughin 2010), and is not a novel form of assessment, (Markulis and Strang 2008), widely employed as an assessment tool for PhD studies (Arico 2021). It is also worth noting that the use oral assessment is popular in other European countries as Germany, Italy etc. (Iannone, Czichowsky, and Ruf 2020; Kehm 2001). Nevertheless, oral exams are relatively rarely utilised in English-based undergraduate programs (Arico 2021; Baghdadchi et al. 2022; Huxham, Campbell, and Westwood 2012). Surveying innovative forms of assessment (Hounsell et al. 2006) found that non-written assessments only accounted for 6.7% of all innovative forms surveyed and that formal oral exams for a single student merely takes up 22% of all the oral forms of assessment confirming the low take-up of oral exams.

1.2 Characteristics of oral exams

Oral assessments can, (Joughin 2010), essentially be categorised into three main types: presentations (talking about a prepared subject in class), interrogations (examiners question students face to face in a viva-like context) and applications (students are required to act as a specialist e.g., consultants, lawyers, clinicians, in simulated professional scenarios). Here we are focussed on the latter two forms of oral exams – interrogations and applications, as the utilisation of presentations is already widely used in our own undergraduate programme.

(Joughin 1998) provided six characteristics or dimensions of oral exams (namely Primary content type, Interaction, Authenticity, Structure, Examiners and Orality) for better understanding of the nature of oral assessments; all of which must be carefully defined for a successful oral assessment. In their discussion (Joughin 1998) highlighted the need for validity, reliability, and fairness in oral exams which was further explored by the same author (Joughin 2010) and more recently by (Akimov and Malin 2020).

1.3 Comparison between oral and written exams

Written exams are the most pervasive form of assessment in most subjects, particularly STEM courses (Baghdadchi et al. 2022), whose most common feature is its convenience (Muldoon 1926) allowing for the efficient and effective assessment of large number of students simultaneously (Dicks et al. 2012; Kang et al. 2019) without too much time and effort cost. Furthermore, written exams are regarded as objective since all students are offered the same set of questions in the same time period (Kang et al. 2019). Nevertheless, in recent years, written exams have been criticised for not be able to assess the deep understanding or detect academic misconduct during exams (Dicks et al. 2012).

In contrast oral exams seem to address the drawbacks of written exams (Dicks et al. 2012) allowing examiners to tell whether a student really understands the knowledge (Kang et al. 2019; Markulis and Strang 2008), and the use of contingent (follow-up) questions is also common to probe students' understanding (Iannone, Czichowsky, and Ruf 2020), allowing the student to express their answers in a more natural way (Huxham, Campbell, and Westwood 2012).

In addition to the above and following the recent pandemic, oral exams should be reconsidered as a possible alternative form of assessment in higher education. Here, the efficacy of oral exams and the feasibility of replacing traditional written exams by oral exams in undergraduate programs, particularly the Mechanical Engineering program at Imperial College London, will be considered.

2 CASE STUDIES OF ORAL EXAMS

During the preparation of this paper a number of case studies were identified in STEM and Business related courses. In particular Mechanical and Electrical Engineering (Baghdadchi et al. 2022), Aerospace Engineering (Rouser 2017), Mathematics (Iannone, Czichowsky, and Ruf 2020), Computer Science (Reckinger and Reckinger 2021), Chemistry (Dicks et al. 2012), Anthropology (Kang et al. 2019), Nursing (Rushton and Eggett 2003) and the summary of case studies in Biology, Medical and Business courses in (Akimov and Malin 2020).

The most significant benefit of oral exams is encouraging students' deep and conceptual understanding of knowledge, thus fostering the desire to learn more thoroughly and interact more proactively with teaching staff (Dicks et al. 2012; Huxham, Campbell, and Westwood 2012; Iannone, Czichowsky, and Ruf 2020; Rawls, Wilsker, and Rawls 2015). Deep learning has also been regarded as a necessity for students' development in the new digital era (Baghdadchi et al. 2022). Moreover, from those cases studied other common benefits noted included: communication skills were practised and developed (Huxham, Campbell, and Westwood 2012), cheating was prevented in exams (Kang et al. 2019), social belongingness was enhanced (Reckinger and Reckinger 2021) and inclusivity etc. is enhanced (Huxham, Campbell, and Westwood 2012).

The dominant disadvantage of oral assessments noted over all types of subjects is the increased stress level experienced by students compared to written exams, which is strongly related to the unpredictability of the novel assessment format (Dicks et al. 2012; Kang et al. 2019). The anxiety associated with novelty was significantly alleviated, in most cases, after the first experience, or if mock and practice opportunities were provided ahead of the formal oral exam (Iannone, Czichowsky, and Ruf 2020; Kang et al. 2019; Rawls, Wilsker, and Rawls 2015; Reckinger and Reckinger 2021; Rouser 2017). Additionally, higher anxiety could, in turn, promote students to devote more efforts into deep learning and comprehension for better performance in oral exams

(Huxham, Campbell, and Westwood 2012; Kang et al. 2019). In addition to the high student stress level, some studies reported time constraint difficulty in scheduling oral exams for faculty members (Baghdadchi et al. 2022; Kang et al. 2019; Rouser 2017), as it is not possible to guarantee that large number of students can take oral exams simultaneously with relatively few examiners. (Kang et al. 2019), conversely noted that oral exams would relieve the scoring pressure for examiners compared to written exams possibly outweighing the severity of time organising problem.

Those studies with large student populations (Baghdadchi et al. 2022; Dicks et al. 2012; Kang et al. 2019; Reckinger and Reckinger 2021), tended to use low stakes (around 10%), formative, and pass/fail oral exams, or to replace original low stakes written exams (mid-term) by oral exams, with shorter time, whereas small-class study groups, (Iannone, Czichowsky, and Ruf 2020) implemented high stakes oral exam accounting large portion of the grades. This might be due to time constraint for scheduling with large student cohorts and inability of oral exam to test broad topics covered by each course (Baghdadchi et al. 2022; Kang et al. 2019).

Overall, the case studies identified proved to be successful where most students and staff preferred oral exams to written exams given the considerable benefits, with better performance by students in oral exams. It was notable that there were no studies indicating the implementation of oral exams to be unsuccessful in the end. However, concerns of prejudice and bias towards minorities still existed and were recognised in undergraduate studies (Baghdadchi et al. 2022; Iannone, Czichowsky, and Ruf 2020; Kang et al. 2019) and needed to be addressed. The studies rarely analysed the problems regarding validity, reliability, and fairness of oral assessments systematically, which are major concerns for increased use of oral exams (Baghdadchi et al. 2022; Kang et al. 2019).

3 VALIDITY, RELIABILITY, AND FAIRNESS OF ORAL EXAM

Considering the benefits provided by oral exams as outlined above, they are, still, underutilized largely due to concerns over their objectivity and reliability (Kang et al. 2019). These concerns will be heightened when oral exams are applied to large cohorts of students as found, for example in undergraduate engineering programmes. Therefore, it is necessary to determine whether problems of fairness and objectivity of oral assessments are significant compared to other concerns when implementing oral exams into higher education.

3.1 Problems of validity, reliability, and fairness of oral exam

The three fundamental attributes aligned with any types of assessments: validity, reliability, and fairness (Memon, Joughin, and Memon 2010) are defined as:

Validity refers to the extent to which the assessment would test what it is intended to examine. For example, the design of an oral exam should concentrate on assessing students' mastery of technical knowledge rather than their language expression skills, (Joughin 2010; Memon, Joughin, and Memon 2010).

While (Simpson and Ballard 2005) highlighted the importance of oral exams being well designed to allow comprehensive demonstration of examinees' knowledge it was noted that the case studies identified in Section 2 covered the right content and further stimulated students to adopt deep learning approaches instead of pure memorisation. Nevertheless, the cases studies identified suggested that programs with large student population tend to use low-stakes short oral exams suggesting that it is hard to design oral exams to cover breadth of the whole course, which questions the validity of oral exams to some extent.

Reliability requires the performance of students or results of oral exams should be consistent when (a) exam setting context changes (inter-case reliability), (b) different contingent questions are posed (inter-item consistency), (c) students face different examiners (inter-rater reliability), and (d) judgement from examiners varies as more students are assessed (intra-rater reliability) (Akimov and Malin 2020; Joughin 2010; Memon, Joughin, and Memon 2010).

Reliability is a significant issue in oral exams with different examiners or contingent questions tailored to each student (Memon, Joughin, and Memon 2010), which is normally the case in universities with numerous students. Judgement from examiners might vary as well throughout testing of large student population (Memon, Joughin, and Memon 2010).

Fairness suggests scores should be graded the same if two undergraduates understand the content equally well regardless of any other factors. The face-to-face nature of oral exams might disadvantage student groups due to bias and prejudice from factors such as gender, ethnicity, class level etc. (Joughin 2010; Memon, Joughin, and Memon 2010).

Fairness problems in oral exams are also concerning. Based on a summary of previous research (Davis and Karunathilake 2005), they demonstrated that examinees' features of personality would influence the scores in oral exams. Particular points of concern highlighted ranged from the way of dressing and expression would affect the final grade in oral exams (Burchard et al. 1995; Rowland-Morin et al. 1991). Students from ethnic minorities trained internationally (also people of working class, female students etc.) would experience discrimination in oral exams due to a number of reasons with the authors emphasising that this problem might become more significant with larger populations of international students (Esmail and May 2000; Roberts et al. 2000). These conditions exist in most undergraduate departments in the world with high numbers of students from diverse backgrounds as confimed by (Kang et al. 2019).

3.2 How to ensure validity, reliability, and fairness of oral exam

To ensure validity, reliability, and fairness the multiple suggestions of (Davis and Karunathilake 2005; Joughin 2010; Memon, Joughin, and Memon 2010) are summarised below:

- Increase the number of oral exams for each student and offer adequate questions each time – when more opportunities and questions are provided covering breadth of courses, students' performance is less likely to vary accidentally, which improves the reliability of oral exams.
- Incorporate a panel of administrators or increase number of examiners – administrators or additional examiners could supervise the progress to spot any potential bias to ensure the fairness of oral assessments.
- Formally train the examiners in advance – all the examiners should be familiar with the purpose and rationale of oral exams and be consistent in marking process, especially when additional examiners were from other departments or institutions, to improve oral exam's reliability.
- Use explicit rubrics and criteria – examiners should adhere to rubrics strictly to validate any point afforded for each student rather than their subjectivity. A sample of rubrics is shown in (Markulis and Strang 2008, Table 4).
- Standardise the questions between students – making the styles and difficulty of questions similar across all the students to refine reliability and fairness problems, so that some students would not be disadvantaged by receiving much harder set of questions than others.
- Involve a panel of relevant professors to design the oral exams – the content of oral assessments should only focus on technical knowledge or skills under the scope of courses to ensure the validity.
- Define the language level required for assessments – oral exams should specify the required language level with respect to the learning outcome, avoiding any assessment required for sophisticated speech skills if not obligatory in the aims of courses.
- Post results analysis – the clustering of higher or lower scores in particular student groups need extra attention to avoid discrimination or prejudice and develop model answers based on best performance to examiners to enhance their understanding of marking process.

4 ORAL EXAMS IN UNDERGRADUATE MECHANICAL ENGINEERING

There was very limited literature identified comparing the efficacy of suggested methods in oral exams in undergraduate studies. Therefore, it is hard to determine which method is the most or least effective in undergraduate programs to ensure the validity, reliability, and fairness without any authentic practise. In this section, the feasibility of introducing oral exams in the Mechanical Engineering Department (MED) at Imperial College London (ICL) is explored and described.

4.1 The feasibility of oral exams in Mechanical Engineering

In the MED at ICL, each year group has approximately 200 students from diverse cultural backgrounds. The students take four years to complete a masters level programme, completing 7-10 modules in each year. Currently the majority of modules in each year are assessed by one high-stakes final written exam in the summer term.

Presently, our engineering students are expected to master a new skillset such as active learning, analytical thinking, teamwork, innovation, technical communication, cultural awareness etc. (Baghdadchi et al. 2022; Kamaruzaman et al. 2019), whose prerequisite is deep and conceptual learning approach, which can be greatly consolidated and improved by using oral exams, rather than memorisation (Baghdadchi et al. 2022).

As stated by (Dicks et al. 2012), interaction between students and instructors is “invaluable” in large departments, whereas the engagement and attendance in lectures and tutorials seems to be particularly low in the UK (Iannone, Czichowsky, and Ruf 2020) and the authors have observed that this is an issue in the MED at ICL.

It is thus felt that the implementation of oral exams in ME can help solve this problem because oral assessments could foster students’ engagement as discussed in section 2. Additionally, students are likely to miss synchronous connections in programs with large student population following pandemics (Reckinger and Reckinger 2021), and this has been found during remote learning in 2020-2021 and some current online courses in the MED. With the help of oral exams, students would be more likely to interact with their peers for oral practise (Iannone, Czichowsky, and Ruf 2020; Rouser 2017) and, minorities in particular, would feel more belongingness (Reckinger and Reckinger 2021), further establishing a more friendly atmosphere in the ME department with its large and diverse population. Furthermore, there are always a number of students with disability or learning difficulties in the MED given a large population, oral exams can be more inclusive for students with disability such as dyslexia (Huxham, Campbell, and Westwood 2012) and provide opportunities for instructors to reach out and help those students with difficulties (Baghdadchi et al. 2022).

Considering most modules in ME only have single exam at the end of the module, the feedback is valuable for students. Currently students do not receive feedback from their exams until at least one month after the exam when marks are published and later still once the solutions are released by which time most students have moved on academically. On the contrary, during most oral exams, students could receive their feedback immediately after their exams (Baghdadchi et al. 2022), which offers a valuable opportunity to receive official feedback from instructors if oral exams were to be used in ME department.

Extra stress generated in oral exams seems to be a major concern, but it is the most significant during the first experience, after which would be relieved (Reckinger and Reckinger 2021), and some methods proved to be effective alleviating stress, as discussed in section 2. Additionally, extra stress could be adopted by some students as the motivation to learn more deeply and thoroughly (Huxham, Campbell, and Westwood 2012). "All examinations are stressful" (Davis and Karunathilake 2005), so anxiety should not become a reason for not introducing oral exams to ME department. While time costs could be problematic this can be alleviated utilising the existing tutorial system in the department where each academic tutorial group (around 20 students) has 1-2 tutors, who could be the examiners.

Referencing the successful case studies conducted by (Baghdadchi et al. 2022), (Dicks et al. 2012), (Kang et al. 2019), and (Reckinger and Reckinger 2021), which have similar size of large undergraduate enrolment of students, especially that of (Baghdadchi et al. 2022), whose subject is also undergraduate mechanical engineering, and considering the discussion above in this section, it can be concluded that oral exams are feasible if properly designed.

4.2 How to implement oral exams in Mechanical Engineering effectively

In this section methods for implementing oral exams are considered in terms of the pre-exam preparation, exam conduct and post-exam follow up.

Pre-exam preparation

Given the large cohorts of students in the department it is felt that an individual oral exam cannot take too long without incurring an extremely high workload for faculty members and creating a timetable log-jam. The case studies discussed in section 2 suggest a period of 10-20 minutes for single student in order to both ensure enough time for fully testing the understanding and avoid high workload and management. Clearly the testing of the full coverage of learning outcomes of each module is then not practical and, therefore low-stakes assessments counting towards 5-20% of the final grade in each module is reasonable. This will, additionally relieve the potential stress experienced by students during oral exams and they in turn would still invest in the preparation of oral exams since they still count as "part" of the course.

To ensure the reliability over our large cohort all 10 tutorial groups (20 students in each) should be examined in parallel with the same set of questions or selection of questions. The scope of the exam should be clearly defined and conveyed to the students before hand. To ensure the validity of the exam it should be designed by each module leader/lecturer having the deep comprehension of the topic and the oral exams "fit" with the final written exam. The rubrics and marking criteria should be made clear to improve fairness and reliability, and arrange a training meeting between all the examiners to ensure consistency

Mock exam opportunities or video examples should be available to students during normal or clinical tutorial sessions before the formal assessment, (Baghdadchi et al. 2022), as in the case of past papers in written exams, to familiarise them with new format and mitigate the high level of stress experienced. Providing advice on how to prepare and approach this assessment effectively, such as practising with peers, for students can prove to be effective in alleviating the anxiety, (Rouser 2017).

Exam conduct

At the start of the exam all students in one tutorial group should sit quietly in designated room. Once a student is called, the student will enter another room to start the exam which will last 10-20 minutes. After the student finishes exam, they would be allowed to return to original seat without speaking to others to ensure the content of exam is not leaked to other as yet unexamined candidates. Once the last student finishes exam, all the students in the tutorial group will be allowed to leave the exam room. This type of arrangement not only prevent cheating in exams but remove the opportunity of students speaking in public, which (Rouser 2017) found to be stressful. A similar arrangement could be used to assess a group of students on a collaborative question, (Baghdadchi et al. 2022).

Examiners should employ an informal relaxed tone to relieve the anxiety of students (Huxham, Campbell, and Westwood 2012). In the case of particularly anxious students more innovative methods could be adopted, for example (Kang et al. 2019; Koh, Tai, and Fung 2021) suggest that examiners could sit behind a screen or desk when posing questions. There should be one or two main examiners with an administrator in place to record the details of the exam to maintain the reliability and fairness. Examiners should initially articulate the questions to students and only provide hints, with points deduction accordingly (Dicks et al. 2012), if they seem to be stuck during the question. After answering all the questions the examiners should strive to provide some feedback to students even if scores are not ready yet.

Consideration is being given to audio and/or video recording of the oral exam for future reflection, training of examiners, the demonstration of example solutions and as evidence for possible appeals (Joughin 2010). However we recognise that this may increase stress levels amongst students and at the very least will need the agreement of the student taking part.

Post-exam follow-up

The scores of entire year group should be analysed statistically, to identify if particular groups of students perform consistently well or badly requiring further analysis or investigation to identify the potential cause, (Memon, Joughin, and Memon 2010).

The lack of experience of oral exams in the department by staff and students necessitates a survey of the students' perspective of the oral exam process for further modification and improvement as conducted in many case studies identified in section 2. The survey derived from (Iannone, Czichowsky, and Ruf 2020) can be adopted that queries students' perceptions of their impressions of the process, comparison with written papers, pre-exam preparation (e.g. mock exam), the conduct of exam and the role of the exam in their learning process.

5 CONCLUSION

A survey of case studies revealed the effective and successful introduction of oral assessments, highlighting the considerable advantages of oral exams, such as fostering deep learning and communication skills. Problems of validity, reliability, and fairness of oral exams, however, could become barriers to the introduction of oral assessments if not considered properly; none of the literature surveyed systematically ascertained the validity, reliability, and fairness of oral exams.

While it is recognised that oral exams could not fully replace written exams, the benefits provided by oral assessments outweigh challenges such as stress, fairness, staff/time cost etc. Specific, initial steps on how to incorporate oral exams in the department are proposed and will form a basis for future reflection and publication following a trial.

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Using Machine Learning Methods to Develop Person-Centered Models Predicting STEM Major Choice

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***Keywords**: machine learning, STEM major, person-centered models, explainable artificial intelligence (XAI), educational data science*

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ABSTRACT

Understanding the factors that influence the choice of a STEM major is important for developing effective strategies to increase participation in STEM fields and meet the growing demand for skilled workers. This research is based on the nationally representative data of 25,206 students surveyed in the High School Longitudinal Study of 2009 (HSLS:09). The HSLS:09 includes longitudinal data from 9th-grade students through their postsecondary study. First, we use machine learning to predict who is going to opt for a STEM major. Then we use interpretable ML tools, such as SHAP values, to investigate the key factors that influence students' decisions to pursue a college STEM major. We identified with a relatively high degree of accuracy the students who will later choose a STEM major, namely our CatBoost classifier achieved an AUC score of 0.791. Moreover, by interpreting the model, we find that having a science or math identity, as well as demographic characteristics, such as gender and race, play important roles in the decision to pursue a STEM major. For example, Asians are more, females are less likely to consider a STEM major, on the other hand, we also find that gender and race do not influence students' science or math identity.

1 INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) fields are critical for innovation, economic growth, and national competitiveness. However, the limited number of students in STEM majors and professions and the underrepresentation of students in these fields is a persistent challenge. To address this, it's essential to understand the factors that influence students' decisions to pursue a STEM major. By identifying these factors, policymakers and educators can develop programs and strategies to increase participation and diversity in STEM fields, meeting the demand for skilled STEM professionals from the workforce.

Several studies have investigated the factors that influence students' decisions to pursue a STEM major. For example, Wang (2013) found that intent to major in STEM is directly affected by 12th-grade math achievement, exposure to math and science courses, and math self-efficacy beliefs. Sahin et al. (2018) found that males and Asian students are more likely to pursue a STEM major. Moreover, they reported that students, who engage in more STEM project-based learning activities, achieve higher GPAs, receive increased encouragement from parents and teachers, exhibit greater math/science efficacy and interest, are more likely to choose STEM majors in college. In a very recent and closely related work by Chang et al. (2023) utilized the HSLS:09 dataset and employed a decision tree to predict STEM major choice. They found that calculus credits, science identity, total STEM credits, and math achievement are the most influential factors during high school years of college STEM major selection. Similarly, Kurban et al. (2019) used structural equation modeling to understand STEM readiness and intention to pursue STEM fields, also by relying on the HSLS dataset. The authors found that STEM major selection is primarily influenced by STEM readiness, math/science interest, and self-efficacy.

Here, we aim to use machine learning (ML) models to predict which students are likely to opt for a STEM major and investigate the key factors that influence students' decisions. To achieve this, similarly to Chang et al. (2023), we analyze the nationally representative HSLS data set, which tracks a cohort of students from the beginning of high school to post-secondary education. By leveraging this data set, we can develop a predictive model that identifies the most critical predictors of STEM major selection.

To gain further insights into the mechanisms underlying our predictive model, we will use interpretable ML/explainable AI tools, such as SHAP values. These tools allow us to identify the most important predictors and how they influence the model's output, i.e., students' decision to pursue a college STEM major.

Previous studies in the field have predominantly relied on classical statistical methods like structural equation modeling, logistic regression, or basic ML techniques such as decision trees. In contrast, here we employ advanced ML techniques, specifically CatBoost for modeling purposes and SHAP values for interpretation, thereby providing a more comprehensive and nuanced analysis of the data.

2 DATA

This study is based on the US nationally representative data of the High School Longitudinal Study of 2009 (HSLS:09). The HSLS:09 includes longitudinal data from 9th-grade students through their postsecondary study. The data were collected in five waves: base year (9th grade), first follow-up (11th grade), high school transcript (12th grade), second follow-up (3 years after high school), and post-secondary transcript (4 years after high school). The variables include the results of surveys (with students, parents, teachers, administrators, and counselors), assessment tests, and transcripts.

The original dataset contains 25,210 rows and 4,014 features, however, there is a great deal of redundancy in the features (e.g., the same questions are asked in multiple collection waves). Hence, to avoid overfitting and to get easily interpretable results we selected a subset of 104 features, aiming to have variables from all groups of variables and to have a relevant but rich set of variables. The selection contains 6 **personal** features (e.g., sex, race, socio-economic status), 8 **high-school related** variables (e.g., geographic region, avg. caseload for counselors), 12 **general** features regarding the students' **personality/expectations/lifestyle** (e.g., the scale of school motivation, the highest level of education student indicated will meet minimum requirements, hours spent playing video games on a typical schoolday), 67 **math and science** related features (e.g., the scale of student's mathematics/science identity, math assessment score, teacher makes science interesting), 10 **transcript** variables (GPA in different courses), and finally a **target variable** that indicates whether the considered major upon postsecondary entry is in a STEM field.

3 METHODOLOGY

3.1 Modeling

In this study, we utilize gradient-boosted tree algorithms, such as XGBoost and CatBoost. These algorithms have been shown to achieve state-of-the-art performance on tabular datasets as they often outperform the most recent deep learning models (Grinsztajn et al. 2022). Gradient boosting is a type of ensemble learning method that involves combining several decision trees to create a stronger, more accurate model. Here, we assume the reader is familiar with the basic concepts of machine learning, for a great overview see the book of Hastie et al. (2009).

3.2 Evaluation

To evaluate the performance of our models, we employ a 5-fold cross-validation strategy, which involves dividing the dataset into five equal parts and using four parts for training and the remaining part for testing. We repeat this process five times, each time using a different fold for testing and the other folds for training. This method allows us to estimate the model's performance on unseen data.

For binary classification, we use accuracy and AUC (Area Under the Curve) performance metrics. Accuracy measures the proportion of correctly classified samples, while the AUC measures the ability of the model to distinguish between two classes, with 1 indicating perfect performance and 0.5 indicating random guessing.

For the regression models, we used two performance metrics: coefficient of determination (r^2) and predictive power score. The r^2 metric measures the proportion of variance in the target variable that can be explained by the model, with a value of 1 indicating a perfect fit and 0 indicating no correlation. The predictive power score (PPS) shows the ratio of how much better the model performed compared to a baseline (naïve) model, which always predicts the median of the target variable. The value of PPS ranges between 0 and 1 and it is defined as follows: $PPS = 1 - \frac{MAE_{model}}{MAE_{naïve}}$, where MAE is the Mean Absolute Error. For a great overview of evaluating ML models, we refer to the book of Zheng (2015).

3.3 Model intepretation

To gain insights into how our ML models make predictions, we utilized two techniques: built-in feature importance and SHAP (SHapley Additive exPlanations) values. The built-in importance metric is calculated based on how much the model's performance improves when that feature is included.

In addition to the built-in feature importance, we also used SHAP values, which is a state-of-the-art technique for model interpretation. SHAP values allow us to measure the contribution of each feature to an individual prediction. Here, we use SHAP values for the global interpretation of the model, namely, to see how the features affect the model prediction in general. To this end, we study how the SHAP values (impact on the prediction) change as the value of the feature varies from low to high. This plot is referred to as a SHAP summary plot that shows the contribution of the features for each student, where the feature names are on the y-axis and the x-axis shows the feature contribution/impact (SHAP value). For a comprehensive overview of the tools of interpretable ML, we refer to the book of Molnar (2020).

4 RESULTS

Predicting whether a student will choose a STEM major is a binary classification problem, where the value of the target variable is one if the major the student was most seriously considering when first entering postsecondary education after high school was in a STEM field, and zero otherwise. We predicted STEM major choice given that the student enters higher education. Thus, we excluded those students, who did not attend any college and the resulting data set contained 11,550 rows. We have tested multiple machine learning algorithms such as XGBoost, AdaBoost, and CatBoost, and on our data set the CatBoost algorithm achieved the highest performance. The mean cross-validated AUC score (i.e., the mean AUC on the five test sets resulting from the 5-fold-cross validation) is 0.801 (with a standard deviation of 0.007), moreover, the mean cross-validated accuracy of the model is 0.790 (with a standard deviation of 0.006). The results suggest, that it is possible to identify with relatively good accuracy which students will opt for a STEM major.

4.1 Features affecting STEM major choice

Besides evaluating the performance of the machine learning model, understanding its underlying mechanisms is critical for gaining insights into the factors driving its predictions. Namely, the goal of this section is to explore how the features influence the choice of a STEM major. Table 1 shows the top 10 most important features according to the built-in feature importance and SHAP values.

Table 1. The top 10 most important features in predicting STEM major choice. The features are ordered by the CatBoost importance, however, their rank according to the SHAP importance is written in parenthesis.

Variable	**CatBoost's built-in importance**	**SHAP importance**
Science ID (11th grade)	8.49	0.33 (2)
Sex	8.19	0.48 (1)
Science GPA	4.64	0.15 (5)
Math assessment (11th grade)	4.51	0.17 (4)
Math proficiency (11th grade)	4.28	0.15 (6)
Science for career	4.19	0.22 (3)
Math ID (11th grade)	3.41	0.13 (7)
Math theta score (9th grade)	3.04	0.08 (15)
English GPA	3.03	0.08 (11)
Math GPA	3.01	0.06 (21)

Source: U.S. Department of Education, National Center for Education Statistics, High School Longitudinal Study of 2009 (HSLS:09)

Table 1 suggests that the most important features are the students' science and mathematics identity, sex, mathematics skills, GPA scores (especially in science), and a binary variable that indicates whether they took a science course because they think they will need it for their career (*Science for career*). The science and mathematics identity variables are based on two other variables: one of them measures whether the students see themselves as a science/math person, while the other one measures whether they think that others see them as a science/math person. Naturally, we find that the higher the value of the scale of science/math identity is the higher the model output is, i.e. the higher the probability of choosing a STEM major is. Hence, not so surprisingly, if high school students see themselves as science/math person, then they are more likely to opt for a STEM major in their university studies.

Furthermore, Table 1 suggests that sex also influences the students' decision to pursue a STEM major. Fig. 1 shows the SHAP summary plot of the top 20 most important features. From the figure, it is apparent that male students (when the value of *Sex* is low, i.e. 0) are more likely to choose a STEM major than females, which is in alignment with related works (Sahin et al. 2018; Vooren et al. 2022).

Besides the importance of science and mathematics identity, the figure also shows, that the higher the score in mathematics (assessment, proficiency, theta score) the higher the (positive) impact on the model's prediction (probability of choosing a STEM major). Interestingly, Figure 1 also suggests that the higher the GPA in English is the less likely that the student will decide to pursue a STEM major. One possible explanation for this phenomenon is that students who achieve high GPA scores in English may be more inclined to pursue liberal arts majors rather than STEM.

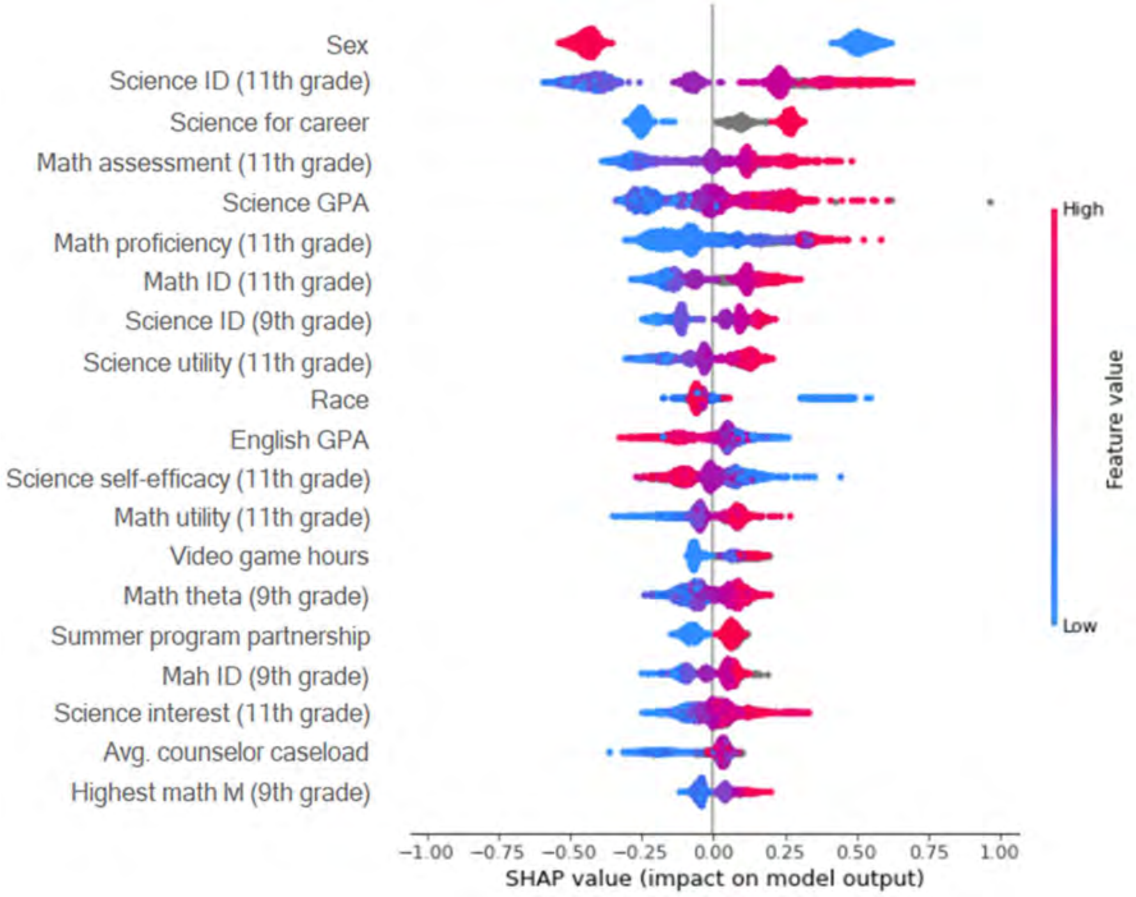

Fig. 1. SHAP summary plot of the 20 most important features affecting STEM major choice. One point is a feature's SHAP value for a student. Overlapping points are jittered to show the distribution of the SHAP values. The features are ordered by their importance. Source: U.S. Department of Education, National Center for Education Statistics, High School Longitudinal Study of 2009 (HSLS:09)

Finally, the reason why *Race* is also among the most influential variables in predicting students' decisions to pursue a STEM major is that Asian students are more likely (46%) to opt for a STEM major compared to other racial groups (20-25%), which is congruent with the findings of Sahin et al. (2018).

4.2 Predicting Science and Mathematics Identity

Our previous analysis predicted STEM major choices, and now we aim to understand the factors influencing students' science and mathematics identities, that are key predictors of STEM major choice. To this end, we trained two CatBoost regression models to predict the values of the scale of science and mathematics IDs in 11th grade, and thus, we excluded those variables that were assessed later on. On the other hand, here we do not filter those students that did not enter higher education, hence this analysis is based on a larger cohort, containing 19,940 rows for science identity prediction, and 20,020 rows[2].

To sum up, for predicting science identity we used the following attributes: *Sex*, *Race*, *Science for career* (takes science bec. needs it for career), *Science to be challenged* (takes science bec. likes to be challenged), *Science bec. does well* (takes science bec. does well in it), *Science can be learned* (agrees that most people can learn to be good at science), *Science self-efficacy (11th grade)*, *Science interest (11th grade)*, *Science utility (11th grade)*. Moreover, for predicting mathematics identity we considered the following variables: *Sex*, *Race*, *Math self-efficacy* (in 9th and 11th grades)*, Math interest (11th grade)*, *Math utility (11th grade)*, *More math bec. good at it* (plans to take more math courses because he/she is good at it), *Math to be challenged* (takes math bec. likes to be challenged), *Math bec. does well* (takes math bec. does well in it), *Math understanding frequency* (how often 9th grader thinks he/she really understands math assignments), *Algebra I* (final grade), *Math proficiency (11th grade)*, *Math assessment (11th grade)*, *Highest math lvl (9th grade)*. These variables were selected based on their correlation[3] with the math and science identity variables. The scale of students' science/mathematics interest, self-efficacy, and utility are composite variables created through principal component analysis, but we also study which subcomponents have the highest importance.

Our results show that the scale of students' science and math identities can be predicted relatively well. Specifically, the CatBoost regressor achieved r^2 values of 0.580 and 0.63 and yielded PPS of 0.392 and 0.423 for predicting science and mathematics identity, respectively. In what follows, we interpret the models to identify which students are most likely to develop science/math identities.

The effect of the variables in predicting science and mathematics identity is shown in Figure 2. The figure suggests that the most influential variables are the composite variables, i.e., self-efficacy, utility, and interest, and the *Science/Math bec. does well* non-composite variables. The most important subcomponents are the binary variables that indicate whether the student is enjoying math/science courses and/or taking

[2] We excluded those rows from the original data set where the science or math ID variable was missing.

[3] Pearson, Spearman correlation and predictive power score calculated with th ppscore Python package

math/science courses because they enjoy math/science – which are both incorporated into the science and math interest variables.

Naturally, the student's favorite subject is also a good predictor of science and math ID, since the favorite subject of these students is typically either science or mathematics. Besides the *Science/Math for career* variables, another important predictor of science/math identity, and hence of STEM major choice, is whether the student thinks that science or mathematics is useful for a future career – which are integrated into the science and math utility variables.

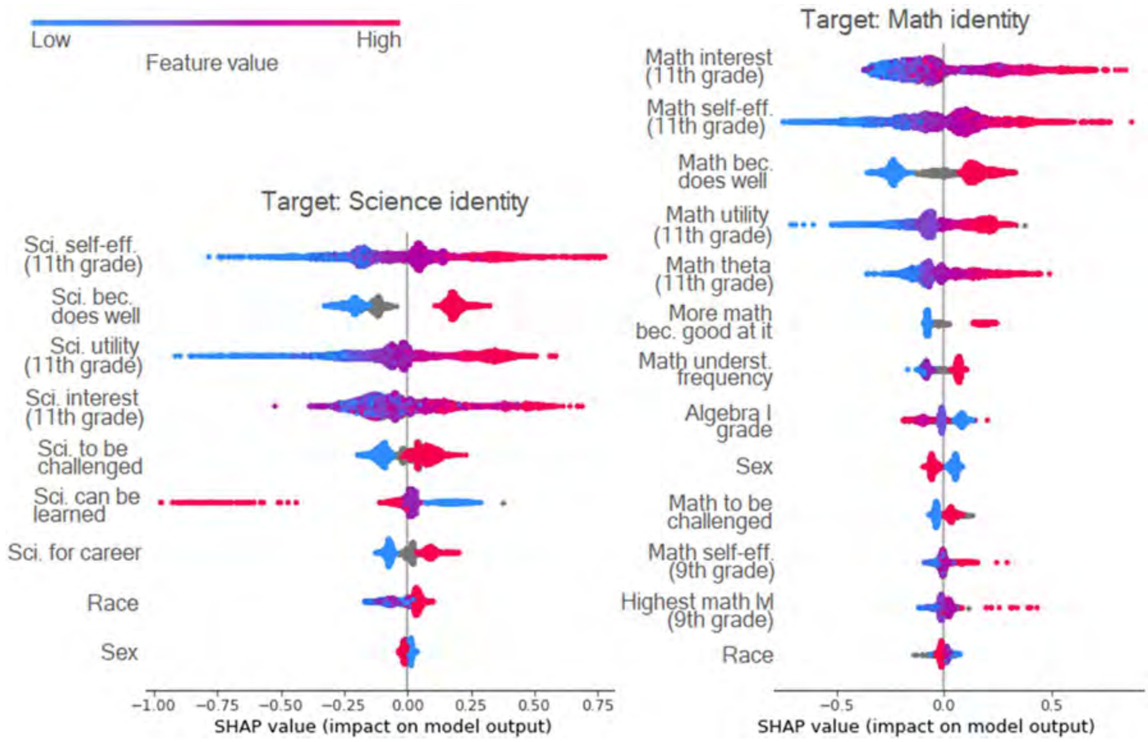

Fig. 2. SHAP summary plots for predicting science (left) and mathematics (right) identity. Source: U.S. Department of Education, National Center for Education Statistics, High School Longitudinal Study of 2009 (HSLS:09)

By comparing Figures 1 and 2, we can conclude that while gender appears to be a significant factor in students' decisions to pursue a STEM major, it is weakly associated with the students self-reported science or math identities. In other words, gender influences the decision to pursue a STEM major, however, it does not influence whether a student considers themself a science/math student.

5 SUMMARY AND CONCLUSION

This paper aims to investigate the predictability of students' choices in pursuing a STEM major and to identify the most influential factors in this decision-making process. Using machine learning models, we achieved relatively accurate predictions regarding which students are more likely to choose a STEM major. Sex, science or math identity, as well as scores and grades in math-related courses and tests, emerged as the most crucial factors in predicting STEM major selection. Subsequently, our focus shifted towards understanding the determinants of science or math identity among students. Notably, while gender significantly impacted the decision to pursue a STEM major, it did not influence the identification as a science or math person. In other words, both boys and girls were equally inclined to be science or math individuals, yet girls were less likely to opt for a STEM major. The primary determinants of science or math identity included enjoyment of science or math courses, academic performance in these subjects, and the perceived usefulness of such courses for future career prospects. These findings contribute to a better understanding of the decision-making processes behind STEM major selection and science or math identity formation, offering valuable insights for policymakers and educators seeking to promote diversity and participation in STEM fields.

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TELL IT WITH COMMITS TO GIT

Recipes for successful teamwork in computer science education

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ABSTRACT

In the realm of higher education, team work is considered a crucial factor in facilitating the development of collaborative and work-life skills among students. Studies have shown that collaborative tasks promote a sense of community, belonging, and well-being among students. However, uneven work distribution and vague team roles can lead to dissatisfaction and reduced commitment, ultimately resulting in assignment failure and impeding progress towards graduation. This paper examines students' feedback on Britton et al.'s (2017) team quality questionnaire, along with their contributions to team performance. Additional questions were added to gauge how students communicate and organize their work within their teams, with an analysis of their activity and contributions measured from their git repositories. Ultimately, this paper presents successful ingredients for team work and suggests strategies for ensuring a positive experience in dynamic team settings. These strategies include clearly defined roles, equal workload distribution, and accountability mechanisms.

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1 INTRODUCTION

Conway's Law points out the resemblance between the software architecture and structure of the organization (Conway 1968). The law suggests that if an organization is divided into teams, the resulting software architecture will mirror the lines of communication and collaboration between those teams. This concept has been observed in practice, when large monolithic software systems transform into distributed microservices, where-after sizable organizations undergo a deconstruction into smaller agile teams that direct themselves and take ownership of their tasks. Furthermore, there has been a shift from extensive planning to the adoption of test-driven development (Kaufmann and Janzen 2003; Gupta and Jalote 2007), to the extent of extreme programming (Bell 2001) where tests play a crucial role as a de facto specification guiding the development process. The delivery of functional end products that meet customer's requirements remains the target but with shortened feedback loops.

Universities must be able to provide industry with new employers that have internalized the principles of the Agile Manifesto (Beck et al. 2001), and are able to form flexible, self-organizing teams (Gren and Lenberg 2020). The influence of Agile Manifesto on flattening organizations has been significant. Flat organizations eliminate unnecessary layers of management, reduce bureaucracy and enable faster decision-making, thus encouraging a shift away from hierarchical structures by empowering teams. Instead of relying on strict top-down control, Agile promotes shared responsibility and decision-making within teams (Conboy et al. 2010), and such Agile methodologies as Scrum or Kanban, to provide frameworks for organizing work, fostering collaboration, and allowing teams to prioritize and manage their own tasks.

In addition to Agile, university Web&Cloud courses introduce DevOps methodology. The main motivation for DevOps is the automation: to achieve continuous integration, delivery, and deployment (CI/CD) pipelines. Automation enables Agile teams to automate repetitive and manual tasks, allowing them to focus more on delivering value and innovation. Besides the automation, DevOps emphasizes collaboration and good communication between team members. The collaborative approach fosters a shared sense of ownership and collective responsibility of the outcome.

2 RELATED WORK

In Tampere University, the DevOps comes in the flavor of GitOps, Gitlab being the version control system integrated with the learning management system in use in courses (Colantoni et al. 2021; Beetz and Harrer 2021). However, DevOps falls short of its full potential due to the absence of continuous deployment (CD) adoption. The introduction of CD is currently postponed until more advanced, master-level courses that use the Kubernetes system. Conversely, continuous integration (CI), which involves the integration of unit and integration tests, is extensively employed. Additionally, the Gitlab issue board, which bears a resemblance to a Kanban board (Nakazawa and Tanaka 2016), is also heavily utilized to foster team interaction and facilitate the progress of work through sprints that are split into tasks shared among team members. Thus, both the Gitlab version control system and issue board serve as tools for monitoring team dynamics and promoting collaboration in ongoing projects.

Parizi et al. have explored the use of Git *”to capitalize on team-aware metrics”* (Parizi, Spoletini, and Singh 2018). The authors advocate for leveraging the power of Git-driven technology and associated features to measure a team member’s contributions throughout the entire progression of the project – not just upon its completion. This approach ensures a comprehensive and precise assessment of individual performance anticipated to foster team-based learning, ultimately resulting in the cultivation of graduates equipped to meet the demanding standards of the software industry.

To investigate students’ group formation, Auvinen et al. studied 150 college students who first individually solved exercises and then worked in teams of three on a class project (Auvinen et al. 2020). The study found that teams with both low-and high-performing students achieved almost the same results as teams with only high-performing students, meaning teams should comprise of both low- and high-performers rather than just one or the other. On the other hand, individual students’ poor time management practices had a negative effect on their teammates’ time management. Most teams assigned tasks to maximize the acquisition of technical skills, rather than training them.

”Can we pick our own groups?” is a common query that arises among students as they anticipate undertaking substantial assignments. Chapman et al. conducted research to examine the impact of group formation, specifically self-selection versus random formation, on group dynamics, outcomes, and students’ attitudes towards the group experience (Chapman et al. 2006). Chapman’s findings suggest that allowing students to self-select into groups may be preferable to random assignment, as it more closely simulates real-world work groups. The research implies that self-selection can contribute to enhanced group dynamics, reduced concerns, improved attitudes, and overall positive student experiences within group settings. However, it is important to note that self-selection may also have certain drawbacks, such as lower perceived efficiency and increased conflict. Thus, careful consideration is needed to balance the benefits and challenges associated with self-selection when designing group formation.

Even if Chapman’s study suggests potential benefits of self-selection, it is essential to critically evaluate the implications in relation to equity. It is worth acknowledging that only a small number of students are fortunate enough to have high-performing and established teams readily available. This advantage becomes compounded if students are repeatedly allowed to self-select their groups. Allowing students to freely choose their own groups can perpetuate existing inequalities, as students with stronger social networks or prior established relationships may repeatedly form high-performing teams, while others may be left at a disadvantage.

2.1 TeamQ questionnaire in a retrospect

Students themselves should have their say on team quality, too. The team quality study conducted by Britton et al. demonstrates the potential of their tailored measurement tool, TeamQ, to assess undergraduate students' teamwork skills (Britton et al. 2017). Their results indicate that communication and problem-solving were the strongest areas of performance, whereas collaboration and team leadership were identified as areas posing significant challenges. Furthermore, the findings suggest that gender may influence individual teamwork skills, with females scoring higher than males in all four areas. This data provides a valuable insight into the efficacy of the tool, suggesting it can be used to effectively evaluate individual teamwork skills in undergraduate education. In the context Web&Cloud courses in Tampere University, TeamQ has been incorporated into reflective post-course questionnaires in a yearly basis since 2020.

In this study, we aim to answer the following research questions:

1. What is the optimal size for a team?
2. How do teams divide work and follow-up on the process?
3. What can course personnel do to ensure better team work experience?

3 RESEARCH CONTEXT

The subject of this study pertains to the Web&Cloud domain, focusing on two consecutive courses: Web for Content Authors and Information Scientists (aka WebCAIS) and Web Development 1 (WebDev1). WebCAIS targets first- and second-year students and concentrates on frontend web technologies, such as HTML, CSS, and JavaScript. Building on this foundation, WebDev1 provides a comprehensive overview of both frontend and backend web technologies, with an introduction to Node.js as a major new technology. This course is intended for third- and fourth-year students who possess a significant programming background, including a fundamental understanding of project work such as Agile project management.

The development process for both WebCAIS and WebDev1 adopts an iterative approach characterized by cyclic design and redesign phases. During the 2019-2020 academic year, the initial stages of development began with the transfer of grading from manual to auto-grading, as documented by earlier studies (Niemelä and Nurminen 2020). After that, there has been a recent shift in focus towards enhancing students' self-efficacy and optimizing their overall learning experience, particularly within the context of collaborative teamwork settings. This shift recognizes the importance of empowering students to take ownership of their learning, foster their sense of confidence and competence, and promote meaningful engagement and communication with their peers.

3.1 Tools used: Gitlab, Plussa and Peer-Review Service

Gitlab plays a pivotal role in final assignments; in WebDev1, also in weekly exercises. Git repositories are created subsequent to the group formation. To streamline project management and task coordination, the Gitlab issue board is recommended as a tool, the rationale being Gitlab's utilization as a version control system, too. This board offers a Kanban-like interface for managing issues. As a primer, students are provided with a few Plussa exercises to familiarize themselves with the issue board. In terms of documentation requirements, groups are advised to employ issues to assign tasks within the board. When utilized effectively, this approach provides a comprehensive overview of each group's progress allowing tasks to be transitioned through various stages such as the backlog "TODOs", then "Doing," and ultimately "Done". These transitions also serve as indicators to other group members not to intervene in ongoing work.

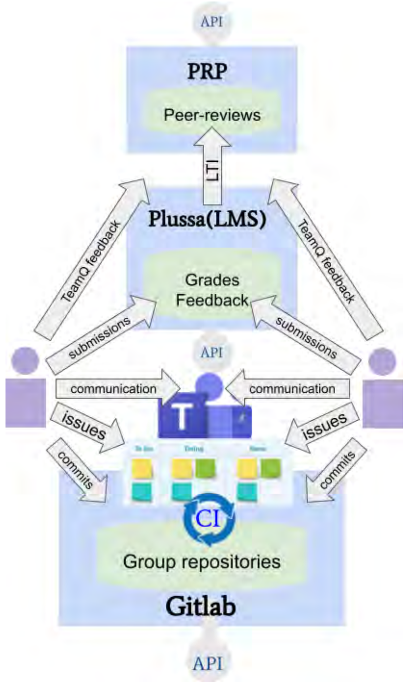

Fig. 1. The teamwork env

The already-mentioned Plussa is the actual learning management system (Karavirta, Ihantola, and Koskinen 2013). Once the assignment is implemented, tested and committed in the Gitlab version control system, the assignment will be graded by giving its Git URL to Plussa. Fig.1 illustrates the teamwork context, which includes work division as agreed tasks in Gitlab issue board, thereafter committing code to Gitlab, followed by submissions to Plussa system, which grants the actual grade that will be stored in the system. In addition to being integrated with Gitlab, Plussa can be extended with other grading modules integrated via Learning Tools Interoperability (LTI) protocol. One such module is Peer Review Platform (Heino 2019), that is used for both intra-course and -team peer-reviewing purposes. In studied courses, the peer-review is intra-team: team members give feedback to each other of the quality of collaboration.

4 RESULTS AND DISCUSSION

After the assignment, students reply to the TeamQ questionnaire by Britton in Likert-scale [1..5], see Fig. 3 and 4. Upon initial observation, it is apparent that students consistently assign significantly positive scores to one another, which can be attributed to a phenomenon called reciprocal mutualism. This behavior stems from the anticipation that providing positive ratings will result in receiving high scores in return. Interestingly, the question regarding passive-aggressive receives the highest score, the question in

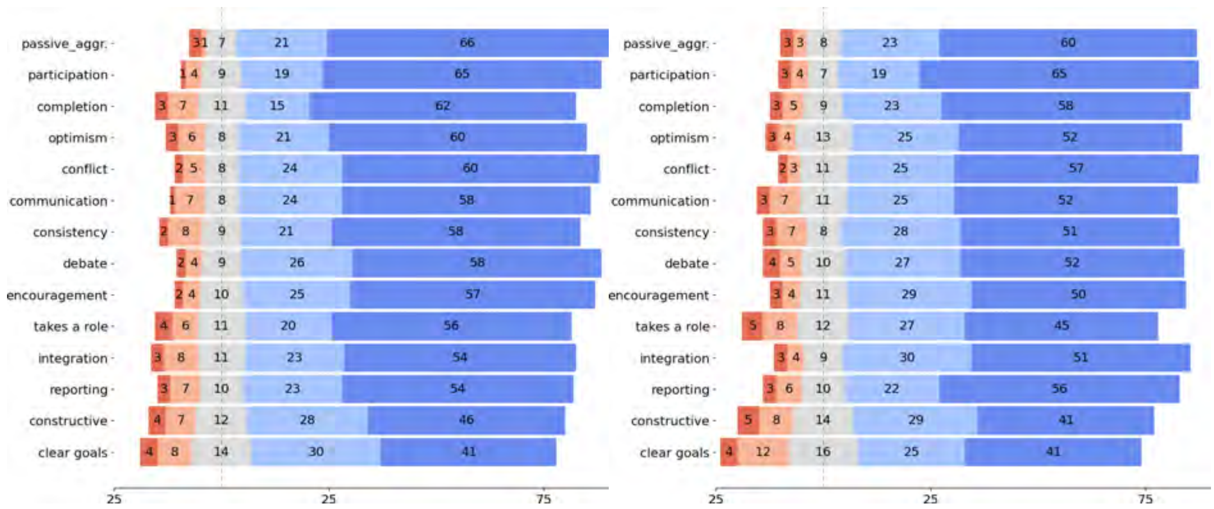

Fig. 2. TeamQ results, WebCAIS (N=320) and WebDev1 (N=512)

its entirety being: *"Displays appropriate assertiveness: neither dominating, submissive, nor passive aggressive"*. Students tend to interact with each other in a pragmatic and straightforward manner, and this specific question tends to elicit thought-provoking and intimidating responses. Consequently, some students feel compelled to seek clarification and confirmation from course personnel to ensure that the questionnaire serves a genuine purpose. Even after the confirmation, the highest scores for one's peers may still be perceived as the safest response to such a "bold" question.

Constructive feedback and clear goals get the least points. Constructive feedback necessitates both courage and a willingness to assume responsibility for the project's success. Similarly, low scores in the clear goals category suggest communication issues and deficiencies in work division. These challenges are indicative of broader project management issues and suggest a need for clearer instructions to be provided.

4.1 Ideal team sizes

Table 1. The votes for the ideal size in both course implementations

Course	N	Votes for [1,2,3,4,5]	Sum	Avg	Std
WebCAIS	605	[17, 27, 137, 36, 2]	219	2.90	0.79
WebDev1	956	[10, 104, 311, 78, 9]	512	2.95	0.71

The result of the ideal team size is clear: three clearly outscores other options between one and five, see Fig. 4.1 and more in detail Table 1. The portion of "two" is significantly bigger in WebDev1, where the first 2020-21 implementations used it as a default size. This observation suggests that either the experience with this size was genuinely positive, or alternatively, participants may have opted for it to avoid expressing any criticism towards their peers. In WebCAIS, the portion of ones is bigger than in WebDev1: 7.8% vs. 2.0%. For the most of the students, the final assignment of WebCAIS is their first

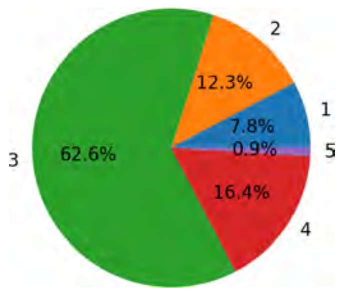

Fig. 3. The ideal team size in WebCAIS

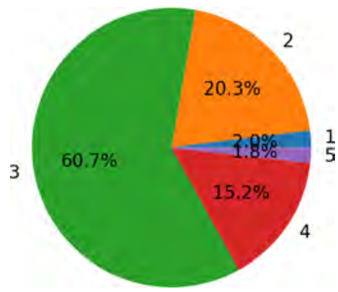

Fig. 4. ..and in WebDev1

group work done in Git, thus the skill levels vary a lot. The experienced students may feel tempted to do everything by themselves and they do not see benefits of teamwork.

Size rationales

The following list summarizes the rationales on each team size grouped by the values of [1..5]; the rationales were asked only in WebCAIS.

1. the students felt frustrated due to lack of collaboration, uneven skill levels, poor communication, and individual members who do not contribute adequately, and these students thus can be categorized as ”disappointed”.
2. the students highlighted optimal scheduling, coordination, task division based on individual strengths, allowing one to focus on JavaScript while the other could contribute to CSS; and suggested pair programming as an approach.
3. the reasons for the ideal team size of three were not very different from two, that is, effective workload distribution, balanced contributions, efficient communication, learning opportunities, and the ability to divide tasks based on individual skills and interests.
4. the students who preferred four highlighted the benefits of even workload distribution, flexibility in collaboration, reliability, technical expertise, and balanced workloads.
5. only two students rationalized for their ”fives” by emphasizing creativity gains and probability of getting a functional group even if members were selected at random.

Even if a larger team means less work, students did not automatically up-vote it, for the downsides, such as the challenges in coordination, started to weigh more. There are more opinions, ideas, and perspectives to consider, leading to longer discussions and potential conflicts. Students also highlighted the risk of uneven workloads: with a group of four, five or bigger, there is a higher chance of having an uneven distribution of workload. It may be more difficult to divide tasks equally among members, leading to potential disparities in effort and contribution. This can result in some members feeling overwhelmed with too much work, while others may have less responsibility, causing dissatisfaction within the group. Limited participation and engagement are real threats in larger groups, because team members may have fewer opportunities to actively participate and contribute, yet it is worth noting that some members may intentionally limit their participation as a strategy to avoid work (Järvinen, Niemelä, and Virta 2019).

4.2 Git for screening students' input in team work

Table 2 displays the Git commit data including additions, total changes, and the percentage of additions. The data reveals the workload for the assignment in the WebDev1 course implementations are at least 10-fold higher than in the WebCAIS course implementations. Additionally, it appears that the students in the WebCAIS course have a higher proportion of deletions compared to those in the WebDev1 course, which could signal that the students at the WebDev1 course are more experienced coders, and hence, do not need to delete that much.

Table 2. Students' Git commits as additions, total, and percentage of additions

Course	Impl.	N. committers	Avg.add.	Avg.total	Add.-%
WebCAIS	spring-2021	36	431	680	70.4
	spring-2022	35	434	495	65.8
WebDev1	fall-2020	171	10349	12155	90.8
	spring-2021	27	14324	18333	89.5
	spring-2021	71	4738	6556	75.5
	fall-2022	171	4538	5288	75.9

4.3 Work division and follow-up in teams

The question about work division and follow-ups were answered by WebDev1 students only. Dividing tasks effectively is important for the final assignment to succeed. A good work division promotes collaboration, maximizes individual contributions, and ensures the timely completion of project objectives. WebDev1 teams adopted diverse approaches for task division, such as allocated tasks in Agile manner; gave a complete responsibility for specific tasks to a selected member after assessing the complexity and workload of each task versus individual preferences and strengths, made decisions collaborative decision-making, where teams engaged in discussions and decision-making processes to collectively divide tasks; and assigned tasks based on immediate project needs, availability, and skill sets, ensuring flexibility and adaptability; divided tasks in sub-tasks, that were smaller and more manageable.

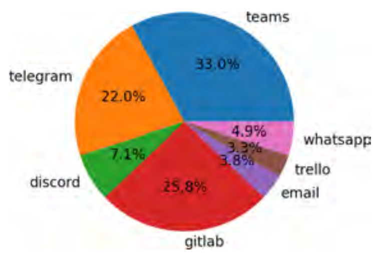

Fig. 5. Follow-up tools

Effective progress monitoring is a crucial factor for successful collaboration and project completion. The teams utilized various strategies, including maintaining open lines of communication through different channels like Teams, Telegram, and Discord (as shown in Fig. 5), to ensure efficient workflow and accountability. These channels were used to exchange updates on completed and ongoing tasks, as well as any difficulties encountered during the project.

4.4 Constructing functional teams

Teams can be constructed numerous ways. During the history of WebCAIS and WebDev1, there have been different experiments. In WebCAIS 2020-2022, groups were the size of three and the roles were fixed: a project manager, an architect and a developer. A project manager was selected based on the Nexus questionnaire (Korhonen 2014) by measuring self-directedness and commitment to studies. An architect was selected based on substance knowledge measured by weekly exercises and self-evaluations. A developer was a novice thought to learn from their peers. In the earlier WebDev1 iterations, students answered a Plussa questionnaire probing their preferences related to group work. Groups were then formed by the course personnel based on their answers. In later iterations, students formed the groups using Moodle virtual learning environment, where students first discuss their preferences and after finding their mates, they register their groups in Moodle group formation activity. Teamless students were grouped by course personnel. The size of three was the default, but as some students had a strong preference to work alone, they were allowed to do so.

In our current method for forming groups, the main criterion is the students' target course grade. While the approach is justified, it may result in groups that are too similar, lacking the necessary diversity and range of skills. In contrast, Auvinen et al. argue in favor of heterogeneity. To achieve a more balanced approach, it is crucial that alternative methods for forming groups are tested (Auvinen et al. 2020).

4.5 ”Mid-point check” and other means to intervene poorly-functioning teams

To prevent students from having negative teamwork experiences, course personnel must monitor the situation, regardless of whether groups are formed by students or the personnel. In an advanced-level web architecture course known as WebDev2, poorly functioning teams were identified and intervened through a mandatory mid-point check. After two weeks of project work, the groups needed to open a Gitlab issue and tag a lecturer. The lecturer then checked Git commits and the issue board to verify that all team members were sufficiently employed. If the check showed adequate activity and fair division of labor, the issue was closed. Otherwise, the lecturer contacted the students and reminded them of the importance of realistic scheduling and fair work division. This intervention often yielded responses even from students otherwise ghosting their peers. This added manual work to the lecturer but was beneficial in catching possible issues with poorly-functioning teams and falling behind the intended group work schedule. It would be beneficial to automate this process, utilizing available data and open APIs in the relevant systems wherever possible.

The findings demonstrated that teams performing well in the mid-project assessment were likely to maintain a high level of performance throughout the project. Conversely, groups displaying limited activity were at an elevated risk of encountering time constraints and experiencing an unfavorable group work experience.

5 CONCLUSIONS

RQ1 Optimal team size: Three outscored other options, in WebDev1 also two scored relatively high, when it was used as the default size.
RQ2 Work division and follow-up: Teams work in Agile manner by utilizing project management tools like Gitlab issue board and strengths of individuals, by communicating via Teams, Telegram or Discord and by adapting flexibly to the situation.
RQ3 Towards better team work experiences: Group formation is crucial, the size matters, as well as students' goals and expectations, such as target grade. Mid-point checks have proven to help, also automatic supervision tools based on git commits and issue boards were anticipated to be beneficial.

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MEASURING SOCIAL IMPACT IN ENGINEERING EDUCATION TO IMPROVE SUSTAINABLILITY SKILLS

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***Conference Key Areas**: Embedding Sustainability and Ethics in the Curriculum, Engineering Skills and Competences*
***Keywords**: social impact measurement, key competences, sustainable engineering education, future skills*

ABSTRACT

In times of social climate protection movements, such as Fridays for Future, the priorities of society, industry and higher education are currently changing. The consideration of sustainability challenges is increasing. In the context of sustainable development, social skills are crucial to achieving the United Nations Sustainable Development Goals (SDGs). In particular, the impact that educational activities have on people, communities and society is therefore coming to the fore. Research has shown that people with high levels of social competence are better able to manage stressful situations, maintain positive relationships and communicate effectively. They are also associated with better academic performance and career success. However, especially in engineering programs, the social pillar is underrepresented compared to the environmental and economic pillars.

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In response to these changes, higher education institutions should be more aware of their social impact - from individual forms of teaching to entire modules and degree programs. To specifically determine the potential for improvement and derive resulting change for further development, we present an initial framework for social impact measurement by transferring already established approaches from the business sector to the education sector. To demonstrate the applicability, we measure the key competencies taught in undergraduate engineering programs in Germany.

The aim is to prepare the students for success in the modern world of work and their future contribution to sustainable development. Additionally, the university can include the results in its sustainability report. Our method can be applied to different teaching methods and enables their comparison.

1 INTRODUCTION

In the last decade, societal and political attention has shifted towards increasing sustainability, which encompasses social, environmental and economic pillars (Linnér and Wibeck 2019). Therefore, the social role of companies is shifting as well. Customers no longer choose products only based on price and function, but increasingly on the values, beliefs and social contribution of the company. This is not specific to one industry and important to survive in the market (Abeysekera 2021). Currently, the focus of companies and the educational sector is mainly on addressing the environmental and economic pillar, but there is still a lack for the consideration of the social pillar.

Social impact refers to the impact that product and service related activities have on people, communities and society (Vanclay 2003; Rawhouser 2019). A company has various qualitative and quantitative methods to measure it for the whole organization, individual projects or activities. It allows reviewing their efforts to create public value and subsequently adjust their offerings. Since universities train the workforce of the future for companies, they cannot escape this trend. It is therefore becoming increasingly important for them to analyze and transparently communicate the sustainability impact (Roorda 2008).

In this paper, we therefore develop first steps for an approach to measure the social impact of our study programs in the department of energy technology (University of Applied Sciences Aachen). We transfer an already established business framework approaches to the education sector.

2 METHODOLOGY

Measuring social impacts is more complex than measuring economic and environmental factors. These are mainly measured quantitatively, e.g. through revenues, expenditures, global warming potential (CO2e), soil toxicity.

In contrast, social aspects are difficult to quantify, therefore surveys are commonly used as a qualitative tool (Arena et al. 2015).

All of them have in common a precise analysis of the company, including the vision, which is the motivating, positively formulated idea of the state you want to achieve with your company. This is followed by the mission statement that emerges as a mandate to make it a reality. In addition, there is afterwards the organization’s value proposition, i.e. a statement that describes the value that a company or a product offers the customer. The next step is the stakeholder analysis. This means gathering information about all the people/organizations (stakeholders) that are affected by the organization and may influence it both positively and negatively. It also helps to identify the beneficiaries of the product/service. Conducting a stakeholder analysis allows to identify their needs and expectations so that we can then address them specifically.

Many also consider the value chain with the additional extension of outcome (short-term effects) and impact (long-term effects). This is based on the theory of change. Key Performance Indicators (KPIs) are then used for measurement, which can be used to determine the current status and progress in relation to the objective within an organization (Arena et al. 2015; Perrini et al. 2021; Abeysekera 2022). These are set up according to the SMART principle: Specific, Measurable, Attainable, Realistic, Time-sensitive (Domínguez 2019).

Currently, there are different approaches to measuring the social pillar and different similar wordings e.g. social value, social performance, social accounting (Arena et al. 2015; Rawhouser 2019).

We decided to use for our approach the recommendation manual of the Erasmus+ project “Social Impact Measurement for Civil Society Organizations (SIM4CSOs)”. It suggest the following basic steps (“related questions”) (SIM4CSOs 2022):
1. Organisational Scope (“Who are we?”)
2. Problem statement (“What we do & why?”)
3. Key stakeholders (“Who we affect?”)
4. Value Chain (“How is it suppose to work?”)
5. Outcomes plan (“How will we measure it?”)
6. Reporting plan (“How will we report?”)

For the following chapter, we have only provided the most important results and selected points that are relevant for understanding the measurement of social impact. Therefore, we have not included step 6 in the publication, as the previous steps should be completed first.

3 RESULTS

For a better overview, we have used the model of the Impact Business Model Canvas (IBMC) as an additional assistance for the documentation (Fig. 1), which we have slightly modified for our needs (Soule 2019). Following steps one to five, we gradually fill it with content. Since we only consider selected aspects, the IBMC is not completely finalized.

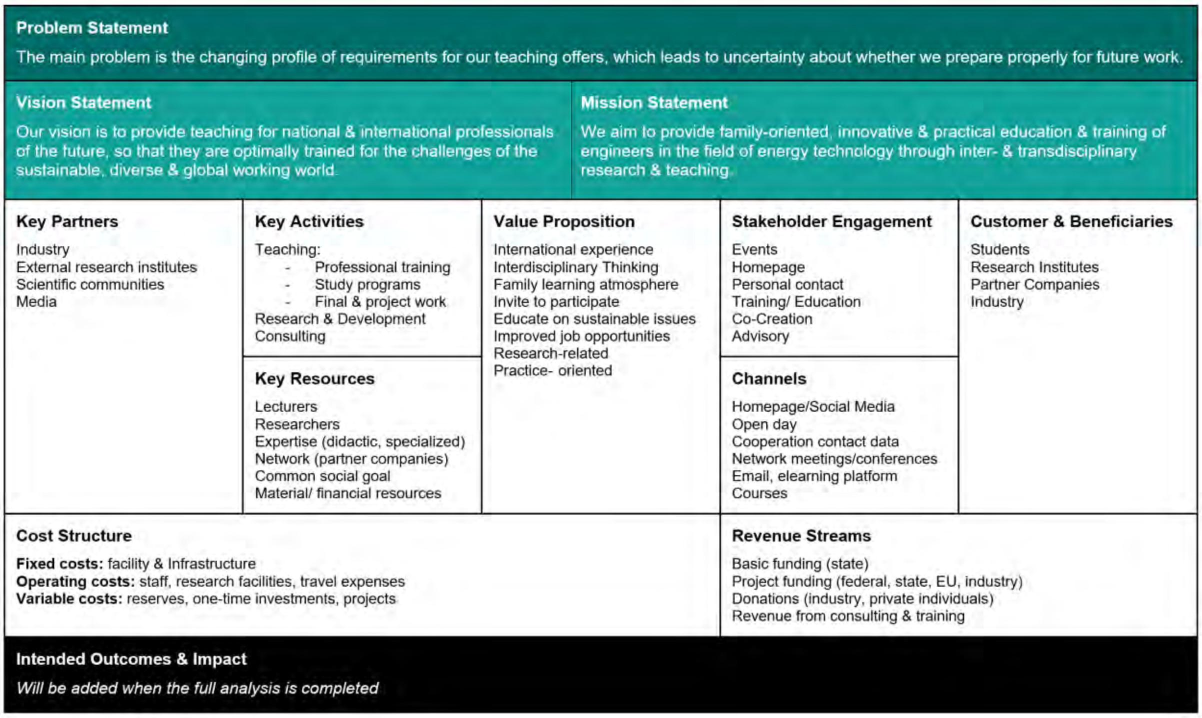

Fig. 1. Impact Business Model Canvas (Draft)

In the first step organisational scope, we first summarized our key resources, channels of communication, cost structure, revenue stream, and added it to the IBMC (Fig. 1). Then, based on the general university strategy of the (University of Applied Sciences Aachen) and in cooperation with the dean's office of the Department of Energy

Technology, we defined the vision and mission statement as well as our value proposition (Fig. 1).
As the second step problem statement, we added the key activities (Fig. 1), which describe what are we currently doing. The main purpose of the faculty activities is to provide education for the future professionals (see vision & mission Fig. 1). Therefore, the relevant teaching activities were identified in more detail on the basis of the module handbooks and program descriptions. We offer in all our programs lectures, exercises, tutoriums, practical/lab courses, guest lectures, project work, thesis writing and field excursions. The related outputs are examination results, practical course certificates, presentations, assignments/reports, feedback, personal notes and finally the engineering degree. For the start of our social measurement, we have limited ourselves here to the offerings in our undergraduate degree programs (mechanical engineering, electrical engineering and industrial engineering).
Next, was the identification of the problem and resulting challenges for our educational offer. The main problem is the changing profile of requirements for our engineering graduates (Heidling et. al. 2019; Giesenbauer and Müller-Christ 2020). It also leads to uncertainty about whether we are preparing them properly for their future work. This is due to the fact that the current teaching focus is mainly on specialist knowledge and not yet comprehensively on a key competence profile (Trilling and Fadel 2009; Heidling et. al. 2019). In addition, it is also changing as a result of globalization, digitization and sustainable development (Giesenbauer and Müller-Christ 2020). For this reason, we must reorient ourselves as a university in order to ensure the best possible education for our students in the future. We summarized these results and included them in the IBMC (Fig. 1).
In the third step key stakeholders, we analysed our stakeholders and segmented them into:

- Internal stakeholder: state government (North Rhine Westphalia, Germany), university management (rectorate), university administration, deanery (faculty management), professors, lecturers, staff, students (national, international), student representation, scientific advisory board, research institutes of the faculty, partner companies
- External stakeholder: industry, research institutes, scientific communities, society, media, public (social Actors & NGOs)

Based on the stakeholder analysis, we classified the stakeholders according to categories key stakeholders, customers & beneficiaries, stakeholder engagement in our IBMC (Fig. 1). Since we only want to give a brief overview of the applied methodology in this publication, we limited ourselves to the beneficiary “students”.
In the fourth step value chain, we started to create the social value chain for our students (Fig. 2). From the earlier mention steps, we had already the input, activities and outputs for the chain. The missing part and additional next step was to focus on our outcomes and impacts. Based on a literature review, we answered the question of what impacts (long-term) and outcomes (short-term) we achieve and how we can measure these impacts/outcomes using indicators. Then we looked at what learning techniques we can apply to influence them positively. To demonstrate the procedure, here an example:
Quality of life is intended as the long term effect through professional development and economic advantage with the degree-specific knowledge, practical relevance and awareness (Tillbury 2011; Heidling et. al. 2019). For the challenges of the sustainable, digitalized and globalized working world, we aim to prepare our graduates specifically

and effectively by addressing 21st century skills (future skills). Three categories of skills are identified (Trilling and Fadel 2009):

- Learning & Innovation – "The 4 C's": Critical Thinking & Problem Solving, Creativity & Innovation, Communication, Collaboration
- Digital Literacy: Information Literacy, Media Literacy, Information & Communication Technologies Literacy
- Career & Life: Flexibility & Adaptability, Initiative & Self-Direction, Social & Cross-Cultural Interaction, Productivity & Accountability, Leadership & Responsibility

This is ensured through our innovative & practice-oriented higher education with the engagement of our industry partners, research institutes and academic policy (Trilling and Fadel 2009; Subrahmanyam 2020). In addition, an expert review, commissioned by the UNESCO, identifies active learning techniques, applicable in engineering courses, which support the development of the 4 C's: group discussions, case studies, critical reading and writing, problem-based learning, fieldwork and outdoor learning (Tillbury 2011).
Due to the preferred requirements of the industry, more employment opportunities arise from the competence profile of the students (Trilling and Fadel 2009; Tillbury 2011; Subrahmanyam 2020). This results in improved financial security.
Furthermore, we aim to improve their personal well-being (Trilling and Fadel 2009). It is influenced on the one hand by the long-term possible improved economic situation and on the other by the direct enrichment through development of self-esteem within the teaching methods (Trilling and Fadel 2009; Tillbury 2011). This leads to the development of internal motivation to acquire new knowledge (Trilling and Fadel 2009).

Based on the research results, we visualised the entire value chain for students in Fig. 2. For clarity and a better overview, we didn't add again the literature sources.

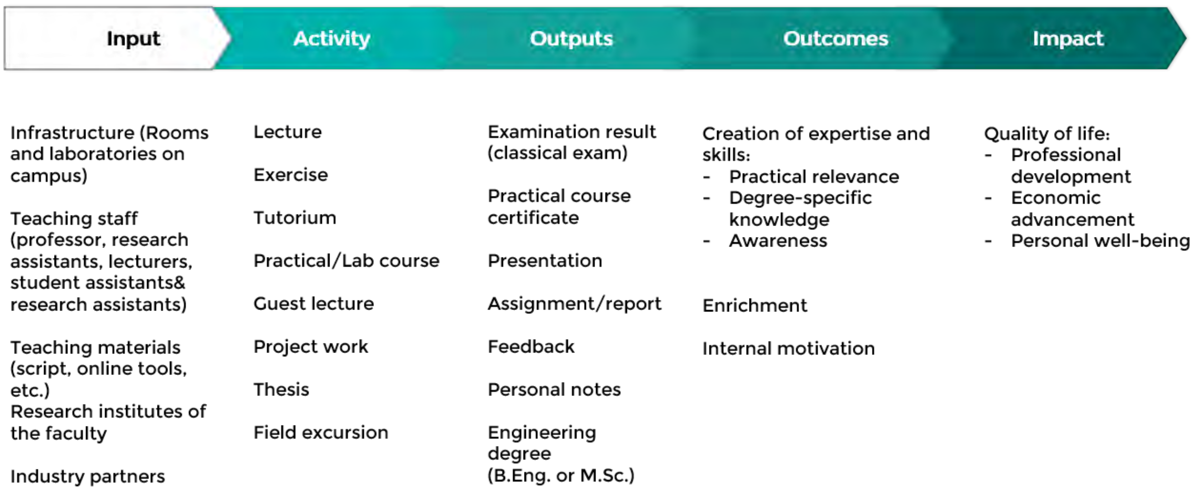

Fig. 2. Students Social Value Chain

In the fifth steps outcomes plan, we created an example of one outcome and one impact of KPI with metric, data source and the frequency of the measurement. Fig. 3 shows the result for the outcome "Creation of expertise and skills", where we restricted ourselves to the specific sub-item "Awareness".

Outcome	Indicator	Metric	Data Source	Frequency
Creation of expertise and skills: - Awareness	Mindfulness & attention for sustainability	% of answer 3 & 4 to the second question (% of students that increased their awareness about ____ after the course)	• <u>Question before:</u> **„How much are you aware of ____?"** (specific topic; e.g. climate change challenges) *1- I never heard of it* *2- I just heard about it* *3 – I know it at little bit* *4- I am full aware* • <u>Question after:</u> **„Do you think this lecture helped you to increase your attention and mindfulness of ____?"** (specific topic) *1- I was already aware about it.* *2- I didn't had knowledge about it and think I didn't gain more attention nor mindfulness.* *3 – I extended a little bit.* *4- I think I am more aware of it.*	Beginning & end of each semester in every course that address sustainability topics

Fig. 3. Example for outcome measurement (Awareness)

For demonstration, we have chosen mindfulness and attention for sustainability as an indicator, because it creates awareness (Yeganeh and Kolb 2009). Typically, multiple qualitative and quantitative indicators should be used, as the more data that is included, the stronger the results. In the metric for the selected indicator, we measure how many students have actually achieved this outcome through our activities, e.g. a lecture here. For this purpose, we ask a short question at the beginning and end of each semester in every course that deals with sustainability.
Fig. 4 shows the result for the impact "Quality of life", where we restricted ourselves to the specific sub-item "Professional development".

Impact	Indicator	Metric	Data Source	Frequency
Quality of life: - Professional development	Critical Thinking	% of courses in the curriculum with problem and project based learning elements	Description module /degree programs	Counting in the accreditation cycle (every 4 years)
		Number of students that have successfully completed the course	Exam result (record/statistics)	During & after every course that used problem and project-based learning
		% of students that increases the competence critical thinking	Professional assessment of the teachers based on the students' self-reflection report and the impression during participation	During & after every course that used problem and project-based learning

Fig. 4. Example for impact measurement (Critical Thinking)

4 OUTLOOK

With the present results, a first foundation for measuring the social impact for students has been created. In a next step, the not yet considered outcomes and impacts in Fig. 2 will be developed and subsequently added to Fig. 3 & 4 accordingly.

This is done by setting up the desired competence profile for our graduates on the basis of an extended multi-criteria literature research and by weighting the individual facets. In this way, it is ensured that all important required competences have been taken into account. Based on these results, the outcomes, impacts and the corresponding KPIs are determined.

For the collection of the KPIs, the existing literature in the field of didactics, social sciences and psychology is used, as there are already established methodologies in this field available through serveral research studies. Subsequently, the evaluation queries, graduate surveys and module descriptions are consulted for data collection of the results.

In order to ensure that the state of development doesn't have to be recorded manually in the future, it is planned to establish a database for collecting the data. This way, the existing data will only have to be imported in the tool, e.g. evaluation results via Excel or module descriptions via pdf, and there will as well be a manual input field.

The next step is to align the results and impacts with the relevant SDGs to ensure that we are making a positive contribution to these goals. Both direct and indirectly influenced impacts will be recorded and benchmarked against previous results. It facilitates our communication with the public through our sustainability report and our channels (Fig. 1). The report will be produced within the framework of the accreditation cycle and is important to present the progress of continuous improvement in a measurable and transparent way.

Subsequently, the approach developed to measure our social impact will be discussed and reflected upon with internal stakeholders in order to further improve the results achieved so far.

Therefore, a teaching survey will then be conducted in the faculty to find out which teaching methods are currently used and which competences are already taught in the respective degree programmes. In this way, the applicability of the measurement can be evaluated in an initial trial run and improved if necessary.

Afterward, the first results will be used to evaluate the current status of the study programmes and from this to identify both potential for improvement and to formulate targets and goals for our indicators. Our aim is to establish a baseline teaching quality standard that will help to continuously improve our courses by setting realistic, long-term and small-step targets.

After completing this intrating process for our beneficiaries students, we want to extend our social impact measurement to our other beneficiaries (Fig. 1). For this purpose, the complete process is repeated and adapted accordingly for these groups.

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COMICIR- COMMERCIALIZATION OF INNOVATIVE CHALLENGES FROM INDUSTRY AND RESEARCH

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ABSTRACT

At Linköping university, a model to facilitate impact and bridge the gap between research, education, and business creation, has been developed. It is named "ComICIR", which stands for Commercialization of Innovative Challenges from Industry and Research. The model allows researchers, firms, and students to work in a co-creation process that are built on the following five steps: (1) research validation, (2) idea generation, (3) idea validation, (4) idea evaluation and, (5) innovation strategy. In the paper, we describe the model and analyse how challenges and ideas could be developed and experientially based pedagogical approaches could be adjusted in order to benefit the regional ecosystem of research, education and industry and contribute to reaching increased impact of innovative ideas and ventures. Our main finding is that CBL is beneficial but requires close cooperation between teachers and innovation support actors. Flexibility is needed to

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fit the purpose of the course as well as the needs of the challenge providers. Hence, challenges need to be categorized and qualified to take into account the aim and scope of the challenge as well as its degree of development as this affects how the challenges should be written and treated to get the best outcome.

1 INTRODUCTION

1.1 The need of a working model for collaboration

The global challenges caused by climate change, poverty and health are more important than ever to solve. Furthermore, actors such as the knowledge and innovation centre EIT (European institute of innovation and Technology) Raw Materials, along with the scheme EIT HEI (Higher Education Institute) Initiative promotes “deep tech” as the main remedy to the societal challenges and points in particular at PhD students in deep tech areas as the new entrepreneurs who can save the world. We support the idea that science and research ideas have potential to become remedies to a lot of the current and upcoming societal challenges - from pandemics to digitalization, energy and sustainability transitions. However, to have an impact, research-based ideas need to be packaged and commercialized and as shown by e.g., Toledano et al 2022, this is not always an easy matter. In order to facilitate commercialization, the interaction between research, education and innovation (i.e., the so-called knowledge triangle) is crucial.

Students, in challenge based I&E (innovation and entrepreneurship) courses, get the opportunity to work with ideas within their domain of expertise, and the researchers or external actors involved, get the opportunity to have their ideas tested, validated and evaluated from an entrepreneurship and business perspective. The students leverage their work in case of a business plan or a report that can serve as base for decisions of how to proceed with the idea. In best cases they also get the opportunity to complement their commercial constellations with new team members. Although this setup seems rather straightforward and has been implemented all over the world, the results are not always overwhelmingly good.

The aim of this paper is therefore to describe how we work with challenges and ideas emanating from research at Linköping university (LiU). We analyse how challenges and ideas could be evaluated and how experientially-based pedagogical approaches can be adjusted in order to benefit the regional ecosystem of research, education and industry in order to reach increased impact of innovative ideas.

1.2 About experiential learning

Experiential learning methods originate from the thoughts of Dewey (1938; 1963) and are anchored in the doing and the reflections thereof. Within this pedagogic family we can find pedagogical approaches such as CBL (challenge-based learning) and PjBL (project-based learning). These methods will be briefly described below. CBL is an approach for learning that has become increasingly popular during recent years. A search in the database Scopus on CBL gives that before 2006 less than 20 papers were published and today the number exceeds 400. A search in Google Scholar gives about almost 4000 hits, whereof the vast majority is published 2020 or later. Previous studies (Eldebo et al 2022; Norrman et al 2022) have reviewed CBL-related papers and found that most of them focused on CBL from a student perspective, while both the teacher perspective and the challenge providers (CPs from here on) perspective was not as well studied. However, to be able to conduct this pedagogy, challenges and CPs are crucial. Starting with the challenge per se, it can be defined as a real-world wicked problem that calls for action and is supplied by an external actor (Norrman et al 2022; Gudonienė et al., 2021).

In a recent CDIO-paper (Norrman et al 2022) the authors have focused on challenges and in their study the following important criteria was highlighted: (1) Openness - by means formulated so that the students can take on the challenge and make use of their competences and interests in the development work in, (2) Wickedness - by means of complexity and lack of a preferred solution, (3) Reality - no “made up” problems lacking real needs, and (4) Pedagogical - the challenge need to fit the pedagogical missions of open innovation processes.

In CBL open innovation processes are part of the game and the challenge works as “a lever for boosting/generating innovation and mobilizing teams made up of various profiles” (Gunnarsson & Swartz 2021 p. 7). I.e., the mixture of teams (CPs and learners included) is of importance and hence actors from the entire quadruple helix are wanted - from student/learners to companies, researchers, organizations and even citizens are wanted. The benefits of challenge-based learning include increased student engagement and motivation, improved critical thinking and problem-solving skills, and better preparation for real-world challenges and careers. It also promotes the development of important skills such as collaboration, communication, and creativity.

The teacher role becomes important and in the ECIU context (www.eciu.se), the teacher is renamed into “teamcher”. Previous research (Eldebo et al 2022) defines the teamcher “as an individual who, either alone or as a part of a team, arranges, leads and supports CBL activities” (p 804). Teamchers (Eldebo et al 2022) take on mainly three roles, the teacher, the coach and the organizer of CBL activities. Of these, the first are knowledge oriented (such as the traditional teacher role), the second is oriented toward facilitation and coaching and related to the development process, while the third are directed to organizing the scene for learning, i.e., the creation of challenges and incepting the collaboration with CPs.

In the ECIU context (see www.eciu.eu) CBL has been put forward as the main pedagogical approach, the process starts with the launch of a challenge - a so-called “big idea” out of which the students define the particular challenge or problem that they in their team want to solve. The CBL open innovation process is then conducted following three main phases. The first, the “engage phase” is about identifying the problem and narrowing down the challenge so that it fits the prerequisites of the team. The second is the “investigate phase”, which is about digging out information on context, stakeholders and other aspects affecting the challenge. Finally, the “act phase” is about creation, description, package, and presentation of the solution.

Like CBL, PjBL is a student-centred pedagogical approach. The basic assumption for PjBL is that students are trained to deal with problems, work with external stakeholders and reflect on their learning process. Students are supposed to be active in their learning process. Common aspects of the approaches are according to Gunnarsson and Swartz (2021) the focus on learning outcomes, team operations, feedback and assessment, coaching, challenge, work process and external stakeholders. However, the focus in PjBL is on improving student learning outcomes in relation to science and critical thinking. Its aim and scope is also less open than for CBL. Hence, when CBL strives to find innovation, PjBL focuses more on developing the path of the project, for example a product or a business model, which commonly not include an open innovation process or a start from a big fuzzy idea.

2 METHODOLOGY

This paper is based on literature studies and upon the own practice generated at Linköping university and in the BOOGIE-U project. Regarding the former, peer reviewed literature has been searched in academic databases (e.g., Scopus and google scholar). Main key words have been experiential learning and challenge/project-based learning. Furthermore, we have searched for literature related to industry-university collaboration, regional innovation systems, ecosystems and studies mentioning the so-called knowledge triangle between research/innovation, education and business/trade & industry, using key words such as "commercialization", "innovation" and "industry". Since the guidelines advocate short reference lists, the number of references cited has been kept low. The practice underpinning the model has been applied in several courses at Linköping university and has developed over the years based on feedback (e.g. through interviews) and evaluations. Furthermore, within the BOOGIE-U project, several of the participating partners have worked with challenge-based learning in their courses and events and through the dialogues and development work, experience have been shared among the partners (cf. Norrman et al 2022; Norrman & Scroccaro 2021). As a result of the BOOGIE-U project, the LiU model for supplying challenges from research groups was refined and conceptualized.

3 THE EMPIRICAL WORK

3.1. LiU CBL-based I&E courses

We have in Linköping run CBL-based I&E courses for several years and at different educational levels and during the years improved the practice of how to cooperate with the surrounding regional innovation ecosystem. For this paper we use 3 courses as the empirical development base. All these courses are project courses where students in teams have worked to develop some kind of business related to an external part. Course1, Entrepreneurship and idea development (6 ETCS), a program course given at candidate level, open for several engineering programs and mandatory for one program. Annually it involves about 60-80 students, and about 10-15 challenges. The course is run over an entire semester and twice a year as part of the engineering programs. The CPs are engaged by means that they meet students 2-3 times.[2] Course 2, InGenious cross disciplinary (8 ETCS) project is a free-standing course open for all that have acquired at least 90 ETCS credits in whatever subject(s). The course is run over an entire semester and is given annually to about 40-60 students and about 6-10 challenges are involved. The CPs are engaged by means that they co-create with the students and meet them 3-6 times during the course.[3] Course 3, Innovative entrepreneurship (6 ETCS) is a program course, given at master level at several of the engineering programs at LiU. For a couple of programs, it's mandatory. It is run once a year during the second half of the spring period. It attracts about 70-100 students and requires about 15-20 challenges. The

[2] https://studieinfo.liu.se/en/kurs/teio94
[3] https://studieinfo.liu.se/kurs/799G52

CPs are commonly rather loosely tied to the course and interact with the students 1-2 times during the course.[4]

As can be seen from the above, we handle about 35-45 challenges and CPs per year, which in itself is a great challenge for the involved teamchers. Previously this has been solved through networks and contacts of the involved personnel, however, such organization is heavily vulnerable as it becomes dependent on individuals. Hence, we realized that to continue and to scale up, we needed an established organization. As the creation of such organizations was one of the tasks of the BOOGIE-U project we took the advantage and formalized the work.

3.2 The practical setup of I&E courses

In general, our I&E courses are run as a mixture of theory and practice. CBL is the main pedagogical method for the project work. The read thread is created through events, and these are described below: In Course 1 and Course 3 where the focus is business development, the courses start with an Idea Jam. At this occasion a number of challenges are pitched to the students and groups are formed based on the individual student's interest in the challenges given. The challenges are standardized and structured on the following headlines: (1) Name of the challenge (descriptive), (2) Picture (that relates to the challenge), (3) Background and main problem (the context and what needs to be dealt with), (4) The challenge (open and directed to the students; your challenge is to come up with...), (5) Contact (names and contact info to the CP). In the inGenious course, students apply to a challenge at forehand via the inGenious website.

Shitty prototyping is an event that appears in all courses and serves two main purposes; (1) ideate and create a visual prototype of a possible solution so that minds can join together, and (2) boost the team building process. The workshop as such is a serious play (Norrman et al 2017), where students use crafts material to build prototypes of their ideas. Halfway through the course we commonly arrange a Value Creation Forum, based on the Stanford Research Institute methodology to give, and take feedback. During this seminar the teams give a short 2–3-minute pitch and receive feedback. Finally, there is a graduation event, which contains pitches and a mini exhibition. The program setup differs a little between the courses though, but external actors and the CPs are commonly invited. The group work is reported in case of a business plan or in the inGenious course a project report, which also is handed over to the CPs. The students also write learning reflections and in Course 3 we have utilized the EntreComp framework (Bacigalupo 2020) to aid the reflection regarding attained skills.

3.3 The ComICIR model

Linköping University has a long tradition of cooperation with industry, both regarding research and fundings. One example is the innovation agency Vinnova, and its support schemes for challenge driven innovation. Applying for such funding implies that a consortium of firms and/or public organizations need to back up the research team behind the application. To increase the efficiency and focus on the commercialization processes of the challenges, and to engage students in solving real, complex, interdisciplinary problems that are relevant to commercialization in the

[4] https://studieinfo.liu.se/en/kurs/teio06

challenged driven innovation, we have developed a model where researchers with their research projects cooperate with students in entrepreneurship courses.

Since our courses have an experiential pedagogical approach and aim to offer the students skills and knowledge in I&E processes, it is of high importance that the students get the opportunity to get experience from a sharp and real-life entrepreneurship process, where there also could be opportunities to join the commercial constellation. Furthermore, the researchers can get new fresh ideas of how to commercialize their research and their ideas also undergo a verification process. In the below Figure 1, the process is illustrated.

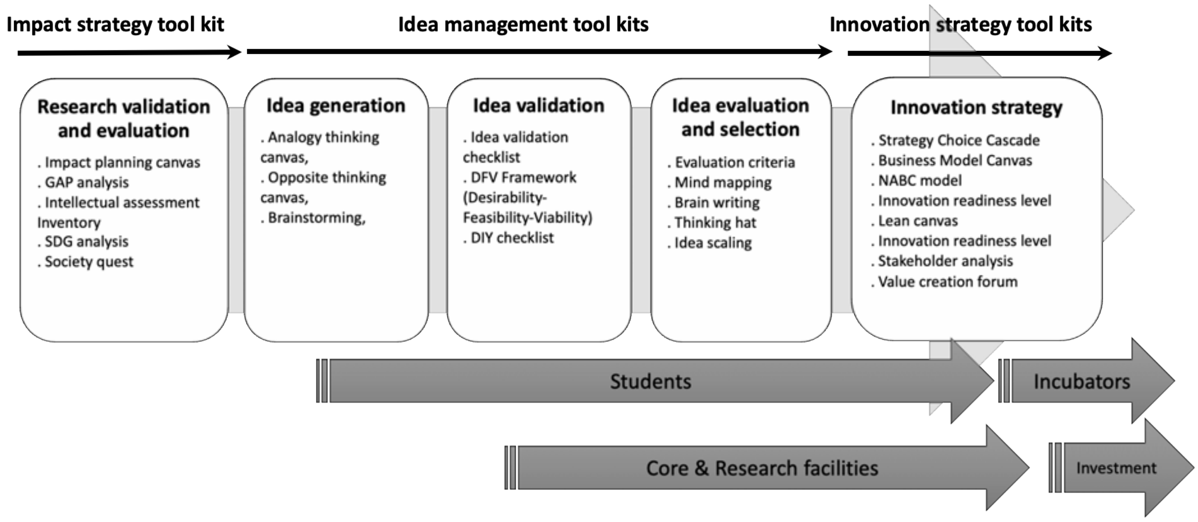

Fig. 1. - Co-creation process for commercialization of research ideas at LiU

The first step is research validation and evaluation, and this is run by the research teams and the advisors and coaches at LiU Innovation. During this part it is decided what applications of the research that could be most suitable for commercialization and the research teams are informed of what they can expect from acting as challenge providers in an entrepreneurship course. Next step is idea generation, which starts at the Idea Jam, where the research teams get a group of students that starts an ideation process. The work is supported by lectures and workshops throughout the I&E course. During this phase students are in contact with the CPs which act as a “sounding board” in the idea development process. At the end of the course the students present their work in case of a business plan, that the research group could either take or leave. If things turn out well, they could start cooperating with the students also after the course- on their own or as a part of matching efforts and activities run by the innovation and incubator support actors. The above figure also shows actors in the regional innovation system such as research facilities, investors, and incubators. When taking in challenges from external parties the process is a little bit different and can best be described as a dialogue to design the challenge. In the courses the same process is applied for all challenges.

4 ANALYSIS

The ComICIR-model has been tested on about 50 cases of various types, whereof at least 50% can be regarded as deep tech or at least technically advanced and business-oriented challenges from start-ups and research groups. The model as such has the potential to be scaled and formalized to reach out to industry, governmental bodies, and NGOs. During 2022 it was tested on research groups with focus on biotech and biomedical engineering. During the spring semester 2023 it has been tested to help new ventures and public bodies such as the region of Östergötland and its municipalities, to find solutions on challenges in line with the SDG 11 – sustainable cities and communities.

In interviews with CPs representing companies, it was revealed that they engage to maintain or get contacts with the university and the students, to get new ideas and solutions and to get information. For challenges to work, it's therefore important that they focus on real problems. Factors that can make companies reluctant is the openness and fuzziness, by means of that they don't know what they will get back. Dialogues with researchers show that they engage as they need help with the commercialisation process, i.e., to define customers and their needs, framing the product, mapping the competition landscape, creating business models, and formulating the impact for the society.

After implementing and testing the model in a strict CBL manner, following the CBL approach of the ECIU in three courses we have realized that CBL - by means of being based on open big ideas searching for any type of solution in an open innovation process - might not be the best way of running the courses to create impact of the all the challenges/ideas given. The reason for this is that there is an immediate risk that the students - and thereby also the solutions - deviates too much from what the idea owners want to have. Hence, if the mission is impact and commercialization, it may be better to narrow down the challenge and abandon a too open aim and scope. In the below figure 2 we have put the pedagogical approaches CBL and PjBL on the vertical axis and the type of idea/challenge on the horizontal. This gives us guidance in how to treat different type of cases for the courses.

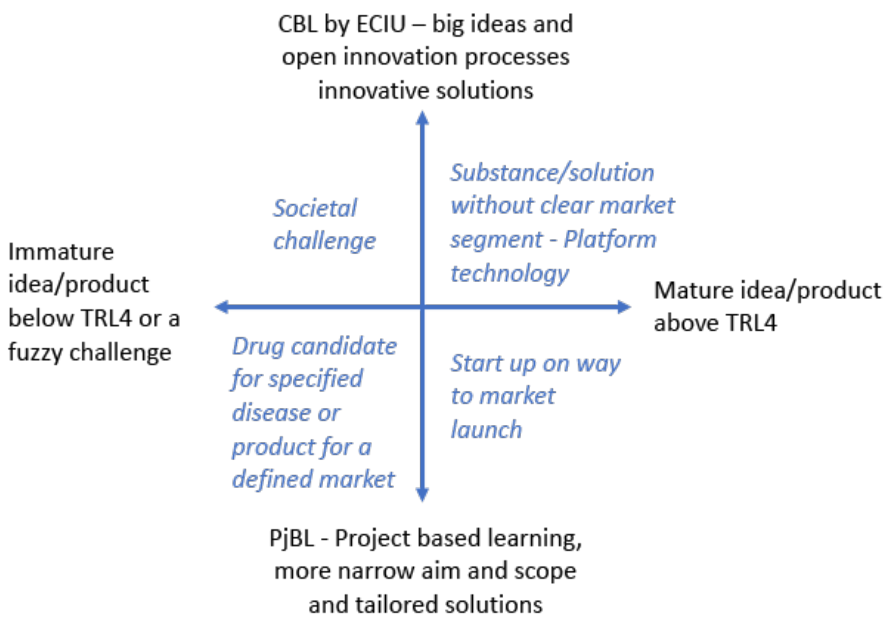

Fig. 2. - Aim and scope of idea/challenge versus pedagogical approach

Type and stage of development, i.e., the innovation readiness level steers degree of openness and unconditionality of the innovation process. I.e., if the idea/challenge comes from a research project and is at an early stage - the CBL process described above might work very well. But if there is a product higher up at the TRL (Technology Readiness Level) scale than 4 (Technology validated in the lab), both students and CPs come better out if the challenge is narrower and more focused on an intended solution. To be able to understand the ideas/challenges is therefore essential and this entails that it is important that teachers, coaches, and CPs, in collaboration can judge the development level of the idea and co-develop the challenge so that the best prerequisites are created and also the degree of to which CBL/PjBL is applied in the process. An immediate implication of this is that selection of ideas/challenges cannot be ad-hoc, neither can they be treated in a similar way - if the goal is to reach impact. To reach this, a more individual and customized approach is needed.

5 CONCLUSIONS

The aim of this paper was to describe how we work with challenges and ideas emanating from research at Linköping university and from external CPs. We have analysed how challenges and ideas could be evaluated and how experientially-based pedagogical approaches can be adjusted in order to benefit the regional ecosystem of research, education and industry in order to reach increased impact of innovative ideas. Our main findings are as follows: (1) The ComICIR model works as it brings together research, education and innovation in an efficient and effective way and creates relevance and meaning for both the students, that gets a sharp learning context, and the idea/challenge providers, that gets new perspectives and basis for further decisions. (2) CBL and PjBL are related learning approaches that fit slightly different purposes. The type of challenge and stage of development are the main parameters to decide how to work with the idea/challenge. (3) The teacher team needs to have both academic knowledge and practical business development skills as they must be able to understand what type of ideas/challenges they deal with. Among the limitations of this study can be mentioned that this is an ongoing work. More tests will be run, and the model will be further developed.

6. ACKNOWLEDGMENTS

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CHANGES IN HIGHER EDUCATION COMMUNICATION PRACTICES AND TOOLS – THROUGH THE PANDEMIC TOWARDS NEW COMMUNICATION MODELS

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The COVID-19 pandemic has significantly impacted traditional modes of communication in higher education institutions, leading to a shift towards remote communication and digital tools. This scientific paper examines the changes in higher education communication practices and tools resulting from the pandemic. The paper analyzes the challenges and opportunities presented by this shift and the ways in which teachers have applied communication models familiar from contact teaching to distance education. A previous review of published literature on adaptations in higher education

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institutions identified key factors for a successful transition to novel distance education communication practices and tools. These factors included effective use of digital platforms, skillful faculty with additional training and support available, and consistent efforts to maintain engagement and community building in the online environment. To determine how teachers have been able to adapt their communication practices and tool use at both the course and curriculum levels in response to the pandemic and whether they see these changes as welcome and lasting, a questionnaire survey was conducted at Tampere University. The results of the survey demonstrated how local experiences reflected the broader changes and contribute to the ongoing discussion about teachers adopting new communication models. However, some teachers expressed a desire to return to pre-COVID-19 practices, as they perceived contact learning as more engaging and effective. Therefore, the authors propose the creation of communication models by teaching staff for their own contexts as a tool for discussing and designing teaching-related communications.

1 INTRODUCTION

Global studies conducted by the International Association of Universities (IAU) have revealed how the COVID-19 pandemic has strongly impacted teaching and learning in higher education institutions (HEIs). (Marinoni, Vant Land, and Jensen 2020)(Jensen, Marinoni, and van't Land 2022) The pandemic effectively forced most universities and other HEIs to extensively adapt to online distance teaching methods and tools, supplanting the more traditional contact teaching on campuses. The comparison of results from two global studies shows that the move to online distance teaching intensified as the pandemic wore on, with the number of surveyed institutions offering online distance teaching increasing from 67% in 2020 to 89% in 2022. The move to distance learning was not complete, as even in 2022, 11% of these institutions still did not offer remote teaching.

The COVID-19 pandemic has brought unprecedented challenges and disruptions to higher education institutions worldwide. As institutions scrambled to adjust to new realities, traditional modes of communication were significantly impacted, leading to a shift towards remote communication and digital tools. This shift has caused significant changes in higher education communication practices and tools, resulting in a need for analysis and evaluation of the challenges and opportunities presented by this change.

In this study, we aim to examine the emergence of communication practices that have been adopted or evolved in response to the pandemic in higher education institutions. To gain insight into the local experiences of higher education institutions in response to the pandemic, we conducted a questionnaire survey at Tampere University. This survey aimed to determine how teachers had adapted their communication practices and tool use at both the course and curriculum levels in response to the pandemic.

Overall, the use of remote communication and digital tools in higher education institutions has resulted in significant changes in communication practices and tools. This paper aims to provide motivation and initial steps for creating context-specific communication models based on the emergent communication practices. The paper aims to contribute to ongoing discussions about the future of communication in higher education institutions.

2 RELATED WORK

Modern higher engineering education includes courses or course elements in which students learn transversal skills related to communication. Oral debates are presented by Mackay et al. (Mackay, Miller, and Benson 2022) as an interesting example of a course element aiming to improve students' communication skills. The focus of our study was on online tools since, due to the inherent nature of transversal skills, students can apply these skills to online communication as well. Students benefit from communication skills in their studies, and these competences are readily transferable to working life. Jalali et al. provide initial work towards a framework for categorizing transversal skills, and as part of their work, they strive to represent transversal skills as overlapping relationships of five themes: thinking skills, ethical reasoning, collaboration (teamwork), communication, and management skills.(Jalali et al. 2022) One of the categories in the list is the communication category, which could include skills related to speaking, writing, and foreign languages. When students acquire these skills, they can coherently and effectively convey their message to others using the appropriate methods and tools. Another category related to communication and thus this study is the collaboration category since collaborative tools such as GitHub or Teams include communication capabilities. Students learn the local organizational cultures of the higher education institutions they are part of, and they are likely to learn the appropriate methods and style of communication implicitly as they interact with other members as part of their studies. Thus, the communication models in these HEIs, either implicit or explicit, influence the students' understanding of appropriate and effective communication.

The work by Vlachopoulos et al. provides an interesting survey of previous research on finding definitions for communication and online communication.(Vlachopoulos and Makri 2019). Communication in the context of higher education includes communication between several roles, including students, teachers, and administrators. Matters that are communicated and methods and tools used to convey these messages differ widely, for example, from administration sending emails to market new programs to prospective students, to teachers and students discussing specifics of an exercise on a course.

Modelling communication processes is a complex undertaking, but this task is aided and guided by a rich history of general communication theories and models from the field of communication studies (Mats Bergman, Kęstas Kirtiklis, and Johan Siebers 2020). Broadly speaking, general communication models have evolved along with advancements in communication theories and technologies. They have evolved from early work theorizing and modelling spoken communication between people to include, for example, linear transmission models useful for modelling mass media and interactive and transaction communication models which include a feedback channel. Asemah et al. provide a concise description of the usefulness of communication models. (Asemah, Nwammuo, and Uwaoma 2022) Communication models enable us to abstract away less important details from the communication processes in real-world contexts to highlight their essential features. Communication is a complex process, and modeling it in any set context, like higher education, requires selecting elements, like communication flows and roles, to be included in the created model. The selections the modellers make highlight what they see as important and thus wish to emphasize. Some common elements present in communication models include:

Sender: The person or entity who initiates the communication and sends the message
Message: The content of the communication that is being conveyed by the sender.
Encoding: The process of converting the message into a form that can be transmitted through a particular communication channel.
Channel: The means by which the message is transmitted from the sender to the receiver. Channels can be verbal, nonverbal, written, or electronic.
Decoding: The process of interpreting the message by the receiver, which involves extracting meaning from the message based on their own knowledge, experience, and context.
Receiver: The person or entity who receives the message from the sender.
Feedback: The response or reaction of the receiver to the message, which is communicated back to the sender. Feedback can be either verbal or nonverbal.
Noise: Any factor or element that can interfere with the communication process and affect the accuracy or clarity of the message. Noise can be physical, physiological, psychological, or semantic.
Context: The environmental and situational factors that can influence the communication process, including the physical setting, cultural norms, social roles, and power dynamics.
Purpose: The reason for the communication, which can include sharing information, expressing emotions, persuading others, or building relationships.

Selected elements are combined to create a high level model of the communication process. An example of a communication model created for the higher education context is the model of learner–learner interaction using video communications (Smyth 2011).

3 METHODOLOGY

A questionnaire survey was conducted at the University of Tampere's Faculty of Information Technology and Communication Sciences to gather data on teaching staff's communication practices and communication tool use, focusing on online communication during courses. The faculty comprises four units: Languages, Electrical Engineering, Computing Sciences, and Communication Sciences.

The questionnaire was designed to provide enough data on communication at the course and curriculum levels and was relatively extensive, with 77 questions and an estimated minimum of 35 minutes required to answer it. The survey questionnaire was designed with optional questions to allow staff members the flexibility to choose which questions they wanted to answer. While this design choice carried the risk of creating a data set including several incomplete answers, it was done to ensure that the answers provided by the staff members were an indication of their interest and perceived value in the subject matter of the questions. The questionnaires' 77 questions were under 10 categories, listed here with the number of questions in each category in parentheses.

- Background information (5 questions)
- General considerations on communication (10)
- Communication tool use during courses (32)
- Face-to-face communication during course (6)
- Communication with TUNI colleagues and contacts outside Tampere University (5)
- Communicating curriculum level matters (6)
- Changes on your use communication tools and your communication practices caused or influenced by COVID-19 pandemic (5)
- File sharing (6)
- Have your say (1)
- Do you want to be contacted for a interview on communication tools and practices? (1)

The categories were selected and the questions were written to cover the aspects of communication models that were presented in the related work section. Other considerations for forming the categories and questions included the findings of previous work on the COVID-19 related global changes in teaching and learning, especially in online communication and tools (Nurminen et al. 2023). The questionnaire was designed to extensively cover matters related to teaching staff's communication practices and their use of communication tools on course and curriculum levels, as well as the changes caused by COVID-19.

To categorize the communication tools and assist in deciding which tools to cover in the "Communication tool use during courses" category of questions, we used a taxonomy for online-based communication technologies presented by Santos et al. in (Santos, Batista, and Marques 2019). This taxonomy was also the motivation behind the inclusion of a separate "File sharing" category.

4 RESULTS

The questionnaire yielded a total of 7 completed submissions from the esteemed teaching staff at our faculty, accompanied by an additional 31 participants who engaged in perusing the questionnaire. In this section, we present the primary findings derived from the answers provided by the 7 respondents pertaining to the initial 8 question categories within the questionnaire.

Background information The responses were provided by a group of highly experienced teaching staff members, comprising three professors and three seasoned teachers and lecturers. Their roles encompassed a wide range of educational responsibilities, including curriculum design for study programs and the planning and instruction of weekly exercise sessions. With regards to communication tools and practices, all but one respondent had the authority or influence to participate in the selection process. According to their feedback, the selection criteria were primarily based on the effectiveness of student engagement and the competencies of the course staff.

General considerations on communication When queried about the total number of hours spent on communication-related tasks per week, the majority of respondents indicated a range between 1.5 and 4 hours. However, it is noteworthy that a respondent from the Communication unit reported dedicating up to 30 hours weekly to communication-related tasks. Interestingly, all respondents except one did not perceive any direct impact of the utilized communication tools on students' learning outcomes.

Communication tool use during courses Email continues to reign as the primary tool for communication with students during courses. Its versatility as an asynchronous communication medium is highly regarded, making it an indispensable choice.

Face-to-face communication during course The participating teachers revealed that face-to-face encounters with their students occurred sporadically and less frequently than on a weekly basis. However, it is worth noting that one respondent reported having weekly meetings with students, indicating a higher level of engagement. Conversely, face-to-face meetings with colleagues were more frequent, with weekly gatherings being the most commonly reported occurrence.

Communication with TUNI colleagues and contacts outside Tampere University Regarding communication on course-related matters with university colleagues, respondents reported engaging via email, Teams, or face-to-face interactions on a daily basis (one respondent) or weekly basis (four respondents), while others indicated more sporadic exchanges. In addition to university colleagues, respondents mentioned interacting with various stakeholders, such as colleagues from other universities, conference organizers, and visiting lecturers from both academic institutions and industry. Communication with these stakeholders involved a range of methods, including email, phone calls, Teams, social media, as well as file sharing through platforms like Google Docs or Dropbox.

Communicating curriculum level matters Participants indicated that discussions regarding curriculum-level matters take place during planning meetings, face-to-face orientation sessions, and through email and Teams communication. The Information Systems department also publishes an annual IS Reviews report, providing a comprehensive summary of research in the field. Additionally, one respondent mentioned utilizing informal reminders during class sessions, such as highlighting skills that are beneficial for students seeking employment in specific countries.

Changes on your use communication tools and your communication practices caused or influenced by COVID-19 pandemic One participant expressed that they have largely reverted to pre-COVID-19 practices, indicating a return to the previous mode of operation. However, another participant highlighted that the current setup remains organized in a manner that facilitates remote student participation. An interesting outcome of the COVID-19-induced changes mentioned by participants was the heightened familiarity with communication technologies like Zoom, which have been extensively utilized as substitutes for in-person meetings.

File sharing Respondents reported utilizing various platforms for file sharing with their students, including Plussa, Moodle, Microsoft's shared documents, and Funet filesender. These platforms served as effective means for disseminating files and materials to their students. On the other hand, when it came to file sharing with colleagues, respondents primarily relied on Teams as the preferred platform.

5 DISCUSSION

Considering that the faculty to which the questionnaire was sent employs approximately 800 individuals, including about 200 teaching staff, the number of submissions received was relatively low. This may be attributed to some staff members perceiving the act of responding as time-consuming. Unfortunately, due to the limited number of responses, it is not feasible to draw broader generalizations from the results. However, it is important to note that the teaching staff members who did participate in the questionnaire predominantly comprised accomplished and experienced professors and teachers from the faculty, with the exception of one teacher at the early stage of their career. As such, the results can be seen as reflective of a deeper understanding of communication tools, practices, and related trends among this particular cohort.

The data collected through the questionnaire reflected the impact of COVID-19 on communication practices and tool usage, aligning with earlier research such as the study conducted by Siegel et al. (2022). (Siegel et al. 2022)'s findings highlighted that many teachers perceived the increased utilization of online teaching and communication tools for distance education as a positive outcome. Furthermore, they expressed a willingness to continue employing these newly adopted practices and tools. However, it is worth noting that the questionnaire data presented a somewhat contrasting perspective. Certain respondents expressed a strong desire to revert to pre-COVID-19 teaching and communication methods. In their responses, these individuals emphasized that face-to-face teaching is more engaging and effective. They highlighted the importance of contact learning, which not only carries a sense of tradition but also enables teachers and students to interact in a natural, human manner, utilizing a wide range of verbal and non-verbal cues to convey information and context. Some respondents expressed concerns that the limited interaction inherent in online settings may lead to disengagement among students.

The development of context-specific communication models by teaching staff for individual courses or curricula can serve as a valuable tool for educational personnel. Such models provide a platform for instructors to discuss and design communication practices and tools that align with their teaching style and specific context. This approach ensures that selected methods and tools effectively reach and engage students. While many general communication models used in communication studies operate at a high level, creating context-specific communication models empowers staff to define communication elements, actions, and requirements at a level that suits them best. This includes defining roles and interactions, establishing timetables, and selecting precise communication tools to be utilized. Staff members can employ familiar terminology and design tools to develop diagrams that visually represent the communication model, making best practices and potential challenges evident for upcoming teaching sessions.

In the authors' experience, communication practices and tool usage related to teaching are often not explicitly designed or discussed. Instead, they tend to rely on what individual teachers have found effective or have grown accustomed to over time. This observation is reflected in the questionnaire findings, where, aside from the widespread use of emails, teachers' responses indicated preferences for communication practices they had developed on their own. Notably, only one respondent had recently received guidance from the university regarding these matters, highlighting the potential impact of institutional support and guidance on communication practices.

When creating context-specific communication models, it is important to determine an appropriate scope for each model. To illustrate this, let's consider the example of lectures within a course, which offers a sufficiently narrow scope for modeling. Prior to the COVID-19 pandemic, these lectures were typically conducted as in-person teaching sessions. However, during the transition to emergency distance teaching, the lectures were moved online. This shift presents teachers with design choices, wherein considerations related to pedagogy and practicality come into play. It is essential to also consider communication aspects within the course design. The move to online lectures can involve the use of either synchronous or asynchronous communication tools, each with their own benefits and challenges (Hrastinski 2008). Selecting between asynchronous or synchronous tools implies the adoption of different communication models. If we start with established general communication models from communication studies, synchronous video conferencing lectures can be described using interaction models, focusing on real-time engagement between instructors and students. On the other hand, asynchronous communication utilizing pre-recorded lecture videos can be modeled using more linear transmission models, where information is transmitted to students in a one-way manner.

In the case of synchronous communication, lecturers have the ability to invite students to participate in lecture sessions through video conferencing platforms, as indicated by some of the questionnaire responses. While this communication model requires real-time interaction, it enables a level of engagement similar to that of traditional in-person lectures, albeit with certain limitations imposed by the features of the chosen video conferencing tool. By creating an interaction model for this scenario, we can identify several key elements.

The basic elements of this interaction model include messages, senders/receivers, encoding/decoding of messages, channels, feedback channels, and noise. Both the lecturer and students act as senders and receivers of messages, as students can communicate by talking or writing messages during the live lecture. The messages exchanged encompass spoken words, non-verbal cues, as well as text, images, and videos shared using the communication tool at hand. The available communication channels vary depending on the features of the tool being used, which typically include video, audio, and screen-sharing capabilities. The lecturer can select specific features to facilitate feedback channels as per their preference. Noise may arise due to technical issues during transmission or ambiguities in the message's terminology.

Some respondents from the questionnaire opted to distribute their lectures as video recordings using asynchronous tools, such as video distribution platforms. Asynchronous e-learning, in this context, requires students to be self-reliant as it does not facilitate real-time interaction. However, it allows students to access the lecture recordings at their convenience. Linear transmission communication models, which do not include a feedback channel, are suitable for describing this form of communication. In the resulting model, the lecturer serves as the sender, designing and recording the lecture (encoding), and submitting it to the video distribution platform (channel). The students act as receivers, accessing and viewing the lecture on the platform. Noise may still occur due to technical issues or difficulties in decoding the message.

To enhance this communication model, it is possible to incorporate a separate communication tool as a feedback channel. This addition can promote student engagement with the lecture by allowing them to provide comments, ask questions, or discuss the content asynchronously. By including this feedback channel, the communication model can better support interaction and foster a sense of engagement between the lecturer and students, even in the absence of real-time communication.

6 FURTHER STUDIES

Based on the findings of this research, there is scope for future work aimed at gathering additional data to enhance communication models in higher education. The current iteration can be viewed as a preliminary step toward developing widely applicable communication models. One potential area for improvement lies in the internationalization of these models, considering the cultural differences in communication practices worldwide. Expanding the research to include collaborations with research partners from other countries would be advantageous in achieving this goal. By doing so, the applicability and effectiveness of the communication models can be enhanced on a global scale.

Another potential avenue for future research lies in the development and utilization of artificial intelligence (AI) systems within higher education communications. The growing trend of AI implementation presents an opportunity to introduce new elements into future communication models. As highlighted by Yang et al. (Yang and Evans 2020) in their work, AI systems, such as conversational chatbots, have already been employed in higher education communications. Training these chatbots using existing chat discussions from previous implementations can enhance their effectiveness in providing timely and accurate responses. Exploring the use of AI systems in higher education communications can lead to advancements in streamlining and enhancing communication processes for the benefit of both students and educators.

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A Theory of Change for Online Accreditation of Engineering Programs: Cultural-Historical Activity Theory (CHAT)

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ABSTRACT

This paper shows how Cultural Historical Activity Theory (CHAT) can provide a practical framework for online accreditation of engineering programmes in South Africa. Far from being inaccessible, CHAT can provide engineering accreditation bodies with a conceptual framework and theory of change for online accreditation of engineering programs. Within the context of program accreditation in South Africa,

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the paper leverages CHAT to comprehend the dynamic interplay of digital technologies as deployed during online accreditation including, amongst others, video conferencing, social media and cloud storage, and how these affect online accreditation of engineering programmes. It is concluded that theory-based research and practice need not remain at a conceptual level but can be used to create concrete solutions to problems, such as the adverse effect of COVID-19.

1 INTRODUCTION

Due to the emergence of COVID-19 in early 2020 and its adverse effect on all facets of human endeavor, there has been a growing quest for the adoption of online platforms for knowledge acquisition and dissemination, of which online accreditation of engineering programs is included. The COVID-19 pandemic has challenged orthodox practices and shown how online platforms can be used in myriad ways (Mentz and De Beer 2021). In today's world of engineering and technology, quality assurance and accreditation is increasingly important. Hence, a strategy needs to be deployed to ensure that the quality of engineering and technology programs is maintained (Trow 1973).

The accreditation of engineering programmes is a critical quality assurance process to ensure that engineering programs meet the global standards developed by the International Engineering Alliance (IEA). In South Africa, accreditation of engineering programmes is carried out by the Engineering Council of South Africa (ECSA) as part of its statutory mandate through its Education Committee (ECSA 2021a). The Engineering Council of South Africa (ECSA) is a signatory of various IEA agreements, including the Washington, Sydney and Dublin Accords (IEA 2021).

Typically, ECSA accreditation of engineering programs involves physical visits to engineering departments at universities over two to three days. During this period, a panel of academic peers and industry representatives scrutinize and evaluate learning materials, visit laboratories, and interview students and staff of the department to be accredited. The objective of the accreditation visit is to assess the compliance of engineering programs with a set of well-defined accreditation criteria, including program structure, graduate attributes, quality of teaching and learning and availability of resources to offer the programs (ECSA 2021b). The Engineering Council of South Africa (ECSA) also makes provision for provisional accreditation of new engineering programs to serve as a developmental exercise to correct any concerns or deficiencies ahead of regular accreditation once a program has produced a first cohort of graduates (ECSA 2021a).

Unfortunately, the onset of the COVID-19 pandemic worldwide in early 2020 disrupted the accreditation of engineering programs by ECSA due to national lockdowns imposed by the government and the enforcement of health and safety protocols that restricted in-person interactions. Consequently, South African universities closed their campuses and moved to emergency online teaching and learning. In addition, most universities requested that scheduled accreditation visits be cancelled or postponed so that the institutions could concentrate on saving the 2020 academic year (Salmi 2020).

To avoid backlogs of accreditation visits to local universities in 2021 and subsequent years, and prevent putting at risk ECSA's credibility and obligations to the IEA, the Education Committee adopted online accreditation of engineering programs, starting in 2021 (ECSA 2021b). A range of requirements and initiatives were proactively put in place by ECSA to enable online accreditation, and this includes developing new policies, implementing digital technologies, and training of stakeholders. As a result of these interventions, engineering programs in a dozen South African universities have been accredited by ECSA using the online modality.

On this premise, this paper aims to study the South African higher education context under the COVID-19 pandemic to critically reflect on ECSA's online accreditation process using Cultural Historical Activity Theory (CHAT). The paper makes a theoretical, rather than empirical contribution and aims to demonstrate how CHAT can be productively employed as a theory of change in a technologically-advancing context. To this end, this contribution is a position paper, where the practice of accreditation is reviewed analytically and then mapped to the CHAT framework to give a system-level understanding of all the elements of the process that can have an impact on its overall success.

Cultural Historical Activity Theory (CHAT) also known as Activity Theory (AT) is a theoretical framework introduced to the West by Michael Cole and popularized by Yrjo Engeström (Nussbaumer 2012). The theory can be adapted and applied to many disciplines in engineering, science, and the humanities. CHAT offers a way of understanding imagined, simulated and real situations that require personal engagement with material objects and artefacts (including other human beings) that follow the logic of an anticipated or designed future model of the activity.

The use of CHAT has increased in educational research over the last two decades. For example, Sumbera (2021) posits that utilizing this activity-based framework to analyze current course structures will allow collective research projects to increase the effectiveness of action-driven justice-centered leaders. In another study, Lupu (2011) found that comparative analysis and diverse ideologies arising from different activity systems appears to be a relevant factor affecting participation in European reform and development processes. Lupu argues that collaborative work is essential for participation and that bringing to light differences makes identities visible, which is an important generative resources for systemic expansion at any level. Also, Patchen and Smithenry (2014) demonstrate how a teacher can link elements within and between a diverse set of participant structures in ways that systematically create real opportunities for student-directed inquiry and collaboration while assuring students learn to act with disciplinary authority.

Like any theory, CHAT is not without its critics. Some have argued that the framework is inadequate for investigating human culture and psychology. Others cite arguments that CHAT is too difficult to learn and not worth the effort to do so (Koszalka and Wu 2004). Yet CHAT remains a popular theory that is currently being employed for different facets of human endeavor such as mobile tool usage, English language teaching and learning etc. (Paskevicius and Knaack 2018).

Engeström posits that CHAT is a model that organizes systems-level thinking and analysis in order to understand an activity occurring within a particular context (Engeström 2007). This paper analyzes ECSA's online accreditation process through the lens of the CHAT activity triangle concepts as depicted in Fig. 1. The approach adopted in this study leverages the power of CHAT to comprehend the dynamic interplay of digital technologies deployed during online accreditation including, amongst others, video conferencing, social media and cloud storage, and how these affect online accreditation of engineering programs.

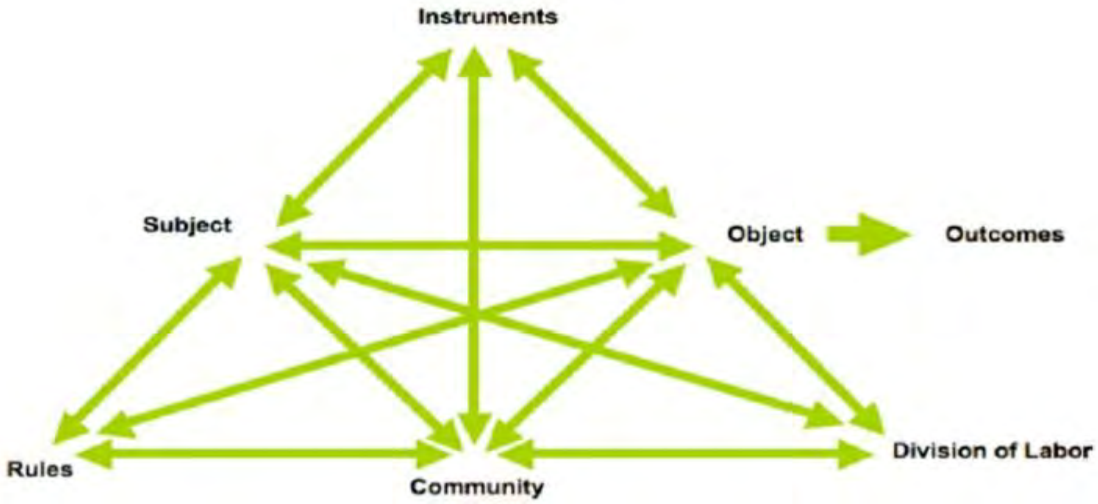

Fig. 1. Cultural-Historical Activity Theory (CHAT) 'triangle' model (Engeström 2008)

In actualizing ECSA's roles and responsibilities in accreditation of engineering programs in South African universities, this paper uses the second-generation CHAT framework proposed by Leontiev (Radford 1998), in which collective activity is the cornerstone of the analysis. The CHAT model, as depicted by Engeström (2008), and as shown in Fig. 1 entails six activity theory concepts as follows:

- Subject
- Instruments
- Community
- Rules
- Division of labour
- Outcome

In the next section, each of these concepts is explained and discussed in the context of the online accreditation of engineering programs by ECSA. The available policies and legal framework as applicable at ECSA or as related to Higher Education in South Africa are invoked for this discussion.

2 APPLICATION OF *CHAT* TO ONLINE ACCREDITATION OF ENGINEERING PROGRAMS

According to Engeström, the *subject* is the individual or group of individuals involved in the activity (Batiibwe 2019). Within the CHAT activity triangle as applied to online accreditation, the university (or faculty) in which the accredited program resides is the subject of the accreditation activity. This subject performs several tasks (Policy E-12- REQ), including preparing the required documentation, hosting the accreditation panel, providing clarification during interviews, guiding the visitation team during the tour of the available infrastructure, etc.

Engeström defines the *object* as the motivating influence behind subjects' participation in the activity (Engeström 2001). From a CHAT perspective, engineering programs are the objects in this regard, although, the students whom the target programs are meant for could also be included as part of the object of the activity.

Instruments are the mediating artifacts used either as physical or psychological tools between the subject and the object (Cole and Engeström 1993). Fig. 2 shows a variety of artifacts used by ECSA in their accreditation of engineering programs. These tools (particularly as stated in E-24-STA) are used in the online accreditation of programs and include cloud file storage systems and video conferencing software. Other examples of digital tools used during the COVID-19 pandemic included Microsoft OneDrive and Teams, Zoom, Google Meet etc. There is a wide array of conferencing and interactive media that could be used as part of the process.

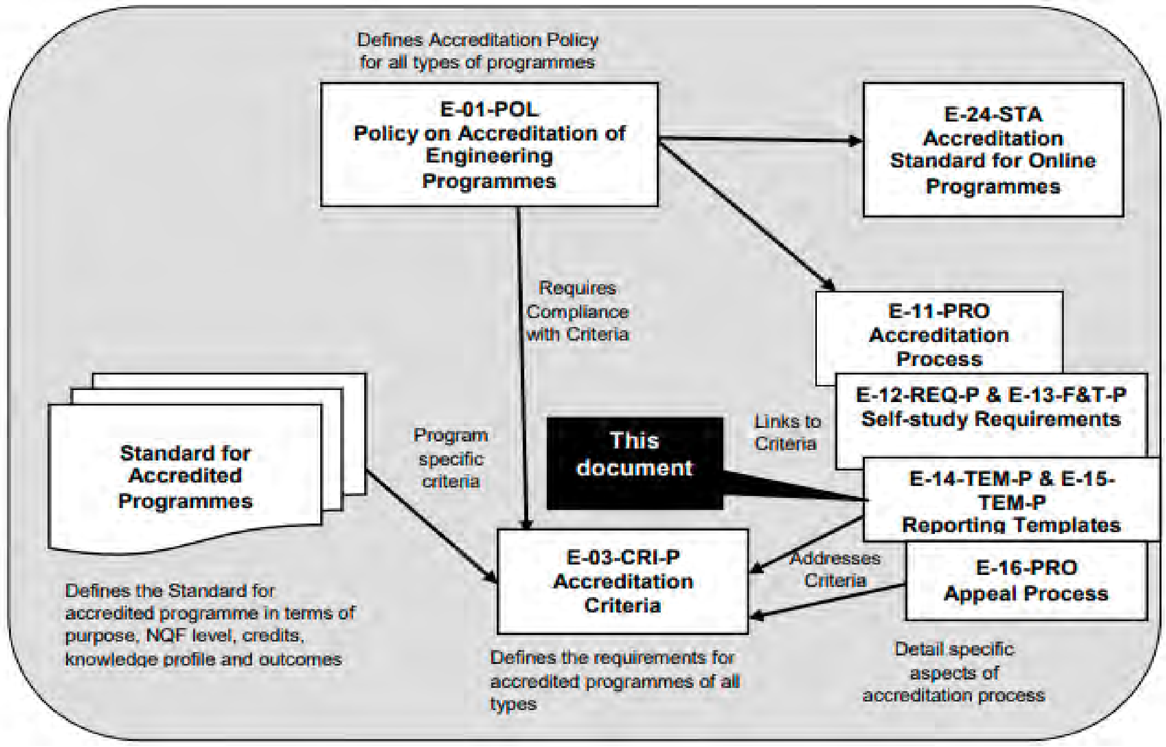

Fig. 2 Documents defining the ECSA requirements for accreditation (ECSA 2021a).

In addition to the ECSA Education policies, the providers developed and adopted several innovative engineering education strategies during the COVID-19 pandemic to assess the Graduate Attributes required by the International Engineering Alliance (IEA) accords. Examples of accepted engineering education strategies to consider ECSA competencies included online assessment and virtual laboratory projects, and simulation technologies, to mention a few. Collectively, the ECSA education policies, the IEA accords and the various engineering education interventions constitute the *instruments* within the CHAT framework to ensure successful accreditation of programmes.

A *community* is the social and cultural group that subjects are a part of, with explicit rules or social norms that regulate and influence its behavior (Engeström 2008). As far as ECSA accreditation is concerned, the stakeholders and organizations actively involved in the accreditation include the accreditation panel, the ECSA administration, the University students, the Council of Higher Education (CHE) and other Engineering fraternities. Also included in the community are supporting staff in the university (or faculty) in which the accredited program resides.

The *rules*, explicit and implicit, vary among the participating units in terms of their specified norms and expectations. In the lens of the ECSA policies, the terms of engagement during accreditation referred to the arsenal of E-series policies available for implementation. Of particular importance are the E-03-CRI and the E-24-STA reviewed and, where necessary, developed from scratch, to prepare for online accreditation during the COVID-19 pandemic.

According to Engeström, *division of labor* defines how tasks and responsibilities are shared among system participants as they engage in the activity. Each participant in the accreditation visit has a specific role. From the ECSA standpoint, E-01-POL (see Fig. 2) describes the responsibilities of the Universities, the accreditation panel, the team and members, and ECSA Administration.

The successful accreditation of engineering programs by ECSA via a virtual medium (online) together with the standardization of engineering programs in South African universities is the desired *outcome*. Through the lens of the accreditation of engineering programs, the product is the recommendation of the accreditation panel to the Education Committee of ECSA, this being the committee of the ECSA council mandated to make the accrediting decision, which the ECSA Council is then required to ratify.

3 USEFULNESS OF *CHAT* FOR CONSIDERING ONLINE ACCREDITATION

The usefulness of CHAT for considering online accreditation resides in its conceptualization of contradictions. Contradictions transform an object, in this case, the successful accreditation of engineering programs, into a “moving, motivated, and future-generating target” (Engeström and Sannino 2010, 89). Finding contradictions in activity systems reveals opportunities for system-wide improvement. Through CHAT analysis, these contradictions offer the potential for new practices for achieving “what is not yet there” (Engeström 2018, 14). An activity system, including one such as the online accreditation of engineering programs, is continuously navigating contradictions within and between the various elements.

Primary contradictions exist within individual elements of the activity system (or triangle). For the purposes of this paper, primary contradictions will not be discussed further, as they do not arise in circumstances of *change*, as is the case when considering secondary, tertiary and quaternary contradictions. Secondary contradictions result when a new element, such as a new instrument, is introduced into an activity system. When this happens, in the form of the adoption of new technologies for example, this may disrupt traditional elements, such as the rules or the division of labor. In the online accreditation of engineering programs, therefore, tools such as E-24-STA (see Fig. 2) make clear how the processes involved are impacted by the new technology – including how the rules and division of labor are affected. In so doing, they are a crucial aspect of the introduction of, in this case, a move to online accreditation. Analysis of secondary contradictions allows for consideration of how the introduction of new tools affects the other elements of the activity. In the case of the move to online accreditation, new *rules* in the form of new and/or revised policies needed to be introduced to resolve these contradictions.

When re-designing an activity system, it is important to avoid tertiary contradictions. These refer to a situation where the object of an older version of an activity system conflicts with the object of a more advanced activity system. In other words, in such an instance, the activity ceases to fulfil the objectives for which it was designed. Use of CHAT as a guiding theory allows for recognition of this potential and reflection on the extent to which the intended object of the accreditation activity continues to be met, even with the introduction of new instruments and rules.

Lastly, quaternary contradictions occur when elements of an activity conflict with elements of neighboring activity systems (Engeström 2005; Mukute 2010). In this instance, it is possible that the online accreditation of engineering programs may align favorably with neighboring activity systems: it may improve the workload imposed on the institutions being accredited, and it may lessen the resource requirements imposed on these institutions. In so doing, CHAT analysis enables consideration of how the online accreditation of engineering programs can better support the engineering education ecosystem and become a “driving force of change” (Engeström 2001, 133).

It is worthwhile, as a last point on the usefulness of CHAT, to mention that the analysis of online programme accreditation through the lens of CHAT also allows an understanding and appreciation of engineering education strategies to ensure the successful accreditation of engineering programmes as the outcome of the framework. The revised ECSA policies, theorised as elements with the CHAT framework, enabled programme accreditation during the COVID-19 pandemic, but also provide a fertile environment to advance engineering education, especially concerning the assessment of the IEA graduate attributes. This is made possible by theorising the particular role that accreditation plays in fostering quality engineering education practices.

4 CONCLUSION

Although CHAT as a theoretical framework for online accreditation as adopted by ECSA was successful, it should be noted that CHAT is an analytical framework (rather than a theory per se) that maps the social influences and relationships involved in networks of human activities. Online accreditation of engineering programs in South African universities using the lens of second-generation CHAT has been proposed in this paper. The exercise revealed the potential of CHAT to provide avenues for improvement of online accreditation processes. Use of CHAT helped to guide the integration of technology into an activity system's content, structure, organization and fundamental characteristics. It also helped to ensure that the outcome of the revised activity remained in line with the original outcome of the accreditation process – and more clearly situated this outcome as being to foster quality engineering education.

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Engineering skills and competences for a more sustainable world

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Abstract

In 2015, the member states of the United Nations agreed that the ideal vision of the world should be achieved by 2030. Halfway through the efforts to reach that vision, and considering the environmental issues we are surrounded by, the need for Higher Education to further incorporate sustainability topics into the curriculum is noticeable.

This paper presents the outcomes of the research through which we aim to make an impact on Higher Education institutions and the ways they are educating and raising awareness on sustainability-related topics. It presents an analysis of the data collected through a survey and focus groups, organised with the students from 63 technical universities all across Europe, in total counting 226 responses. The paper points out the relevance of engineering education on environmental sustainability in

today's rapidly changing, modern world. It also identifies the sustainability-related topics that should be incorporated into the curriculum. Further, it points out different engineering skills and competences needed for a more sustainable world and the ways in which they can be obtained. Some of the skills highlighted as the most important ones are: communication, time management and critical thinking.

The results show a critical imbalance between the practical and theoretical parts of engineering education. It reflects on the possibilities of implementing modern teaching and learning methods, in order to create a more sustainable mindset in engineering, thus making the learning process more engaging and accessible.

1. INTRODUCTION

Our planet is facing massive economic, social and environmental challenges that we can no longer ignore *(*SDG compass, n.d*.).* Over 130 countries strive for net-zero carbon emissions by 2050. Technological innovations will be essential in the backend to ensure global leaders reach this goal. However, in the frontend, there is a strong demand for society to relearn how to live on this planet sustainably as the climate rapidly changes - and education is a key enabler of this transition *(*BCG 2022).

Over the years, Education for Sustainable Development has gained international recognition as an integral element of quality education and a key enabler for sustainable development (UN, n.d.). It utilises action-oriented, innovative pedagogy to transform society into a more sustainable one (Giannini S, 2020). Education plays a crucial role in developing climate literacy, which is essential for driving behavioural change and collective action. Early studies suggest that young people who become climate literate can educate their families, creating a multiplier effect in their communities (Lawson et al, 2019). However, it is important to acknowledge the limitations of Higher Education's role in sustainability (Sterling S, 2021). While some organisations and individuals have been working on the intersection of education and economic, environmental, and social topics, education has not been widely recognized as a solution to sustainability issues.

We identify three primary objectives where education and sustainable development intersect, with education serving as a powerful driver of change:

Objective 1: Assess the current state of the Engineering Education on Sustainable Development (EESD) in Europe and identify relevant sustainable-related topics that addressed in Higher Education;
Objective 2: Define the key engineering skills for sustainable development that can be acquired through Higher Education and explore effective ways of obtaining them;
Objective 3: Determine the methods through which sustainability can be integrated into the curriculum and examine approaches for embedding sustainability principles .

2. METHODOLOGY

The methodological approach of this study was based on the initial quantitative analysis of gathered data, while the final conclusions were drawn using a combination of quantitative and qualitative data. The data were collected through a literature review, which helped establish the theoretical background. Additionally, a survey was conducted to gather qualitative data, and focus groups were organised to further support the development of the final conclusions. The target group consisted of students from technological universities in Europe. The total population of the study comprised 226 students from 63 technical universities in Europe, during the period from November 2022 to February 2023.

All participants of the research were asked about their perception of the current state of EESD and how to bridge the gap between the expected and actual outcomes provided by EESD to students. The research results are presented throughout the paper using various graphs that are relevant to the showcased dataset within each section. For a more in-depth analysis to identify logical correlations, the PowerBI software was utilised. The main dimensions used for analysis were age group, gender, and the participants' graduate status.

Lastly, it is important to emphasise the need for a critical mindset when interpreting the results, considering the benchmark and the average number of students per university that participated in this research. In conclusion, further steps regarding this aspect will be addressed.

3. RESULTS AND DISCUSSION

3.1. Current state of the EESD

Nowadays, more countries say education on sustainable development is reflected in their educational system. However, EESD is often narrowly interpreted, focusing primarily on topical issues rather than adopting a holistic approach that promotes a fundamental behavioural shift towards sustainable development. Higher Education Institutions worldwide are recognising the significance of engineering in addressing the sustainability challenges of the 21st century. As a result, there is growing contemplation of integrating sustainable development principles into engineering curricula, in line with accreditation guidelines (Edmond P. et al., 2010).

Table 1 showcases the state of the sustainable topics tackled in the studies in technical Universities in Europe, with the total percentages given for ratings 1 to 5:

Topic	1 - Not at all	2	3	4	5 - In depth	4 & 5
The UN Sustainable Development Goals	23%	17%	29%	21%	10%	**32%**
Climate change	12%	13%	27%	30%	18%	**48%**
Product lifecycle	14%	14%	27%	34%	11%	**46%**
Design for sustainability	21%	31%	22%	17%	9%	**26%**
Impact assessment	26%	24%	24%	18%	8%	**26%**
Sustainable energy production & management	18%	14%	30%	24%	14%	**38%**

Table 1. Percentages of coverage of sustainability-related topics in studies, on a scale 1-5

According to the data presented in Table 1, technical universities in Europe have main focus on the following sustainability issues: climate change, product lifecycle, and sustainable energy production/management. The table reveals the distribution of grades (specifically, grades 4 and 5) assigned to these topics, with percentages of 48%, 46%, and 38% respectively. Out of all the topics, climate change is the only one which was graded with higher grades by undergraduate students. [17]

The data indicate that the topics currently included in curricula align with the "top sustainability trends" in the global market, such as recycling, reduction of food waste, improved transport and infrastructure, and sustainable materials (McKay B, 2023).

However, the United Nations has raised the question of whether it is necessary to include social and economic aspects in EESD, in addition to the environmental pillar of sustainable development (UNESCO, 2020, chap. 1). The extent to which these topics are addressed in universities is highly dependent on the development state of countries and their "sustainable mindset." Considering the principles outlined in Agenda 2030 and SDGs, which emphasise the need for collective action towards building a better future, it can be concluded that quantifying the extent of the positive impact achieved is challenging due to significant discrepancies between countries in their attention to sustainability matters. This question also extends to EESD.

The **main recommendation,** therefore, is for Higher Education to shift towards a holistic approach that encompasses sustainable development. This entails fostering a more sustainable mindset among students, raising their awareness of the impact their actions have on the world around them through sustainability literacy. To achieve this, educators, educational institutions, and governments need to commit to implementing action-oriented curricula, rather than solely being conveyors of information, and provide appropriate training for teachers.

3.2. Engineering Skills for a more sustainable world

To follow a sustainable development path, it is crucial to undergo a fundamental and transformative shift in thinking, values, and actions for everyone. Multiple studies emphasise that future generations of engineers will not only drive technical innovation but also play a leading role in addressing various social issues (Desha and Hargroves Citation, 2014). They are key actors who can incorporate sustainability into their solutions and transform our current technologies into greener alternatives. This raises important questions: **What** skills and competencies should engineers possess? **How** and **where** can these skills be acquired? Should sustainable-related topics be integrated into engineering curricula, and if so, how?

The literature reveals that future engineers will require a broad range of sustainability competencies and skills to support the SDGs. However, different stakeholders, including students, employers, and academics, may define these key competencies for sustainable development differently (Beagon U. 2022).

According to the presented data on Fig. 1, the majority of respondents indicated that the most relevant competencies for engineers are: critical thinking, sustainable mindset, creativity and innovation, problem-solving, and ability to work in a team, respectively. It is worth noting that there is a slight preference for these top five skills among female respondents, as indicated by their higher ratings of 4 or 5 on the scale. [17]

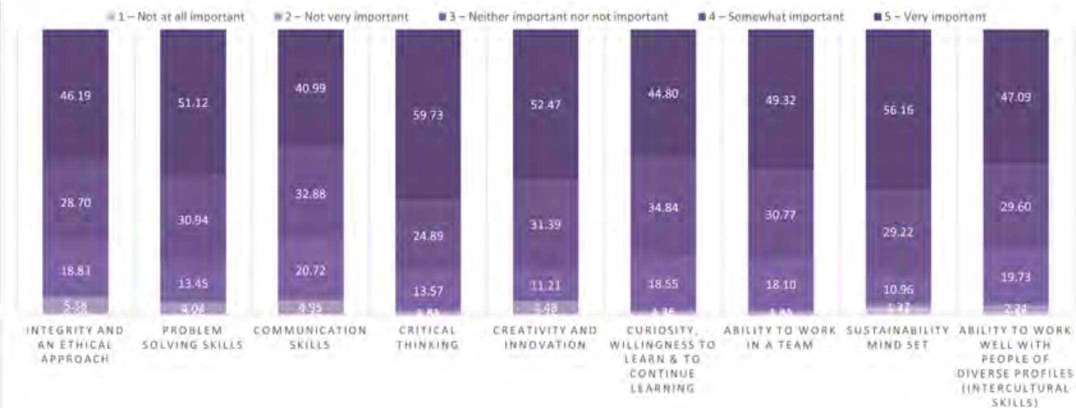

Fig. 1. Histogram showing the perceived importance of the following skills for addressing sustainable development, on a scale 1-5

If we compare the results with the research conducted by the United Nations in 2017 (UNESCO, 2017, pp. 54-56), we can observe that the competencies mentioned align with the "key competences for sustainability" listed in that study. However, these do not replace specific skills required for successful action in specific situations and contexts.Instead, they encompass and have a broader focus (Rychen, 2003).

Based on these findings, it can be concluded that through EESD, engineers in today's society should possess the following abilities:

- Question norms, practices, and opinions, and reflect on their own values, perceptions, and actions, as well as those of society;
- Be self-driven and operate responsibly, considering how everyday actions can contribute to building a sustainable future;
- Use imagination, creativity, and innovation to develop products and services that maintain and enhance the quality of the environment and the community, while also meeting financial objectives;
- Apply diverse problem-solving frameworks to address complex sustainability issues and develop viable, inclusive, and equitable solution options that promote sustainable development;
- Learn from and collaborate with others, understanding and respecting their needs, perspectives, and actions, and facilitating collaborative and participatory problem-solving.

These competencies should enable individuals to establish connections between the different SDGs, allowing them to comprehend the "big picture" of the 2030 Agenda for Sustainable Development. The extent to which these competencies can be acquired through Higher Education varies depending on the structure of curricula in different universities.

The **main recommendation** is for Higher Education institutions to prioritise two critical areas. Firstly, they should focus on providing lifelong education opportunities for current workers. Secondly, institutions should establish a strong foundation for students who will become leaders in the development of future technologies, equipping them with the necessary knowledge and skills. In addition to technical skills, it is essential to foster green skills that centre around teamwork, resilience to navigate ambiguity, problem-solving, and creative thinking. To facilitate a smooth transition towards a sustainable economy, it is imperative for leaders in education, government, and industry to align educational programs and training institutions, ensuring the provision of essential skills.

3.3. Learning methods and techniques for EESD

Until now, little is known about the quality of EESD programmes, the extent of their implementation and their effectiveness in generating the desired changes in learning attainments - knowledge, competencies, values, and behaviours (A. Leicht et al. 2018, chap. 2).

There are multiple activities, learning and teaching methods that can contribute to the development of sustainable skills and mindset. Fig. 2 showcases some of them that students recognised as the most impactful ones, with an average grade from 1 to 5.

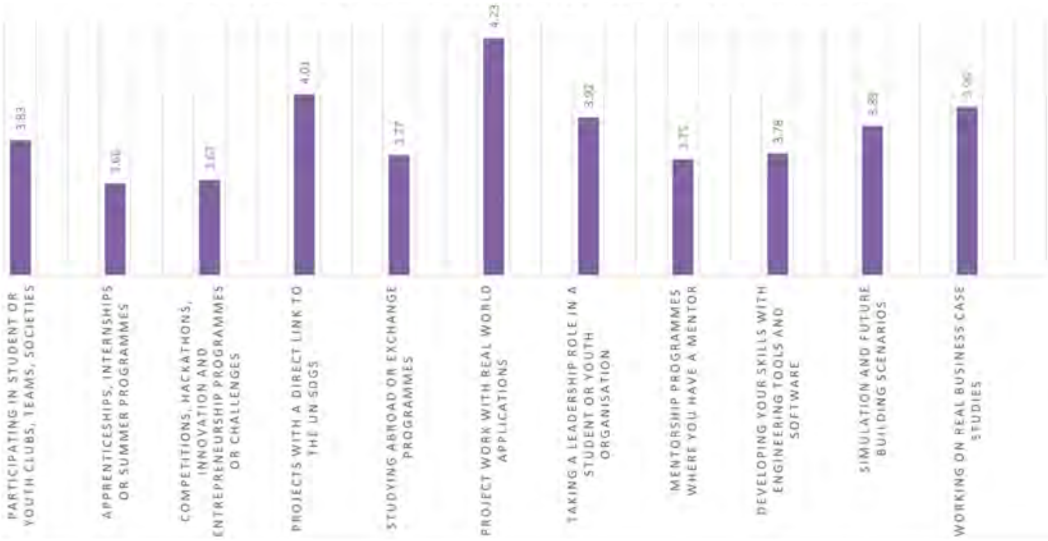

Fig. 2: Impact of different learning methods according to students, on a scale 1-5

The results indicate that the top 5 activities supporting development of crucial skills during studies are as follows:

- Project work with real-world implementation;
- Projects with direct link to the UN SDGs;
- Working on real business case studies;
- Taking a leadership role in a student or youth organisation;
- Simulations and future building scenarios.

Both undergraduate and postgraduate students share a similar opinion on the impact of these activities on skill development, with graduated students slightly favouring the top activities. In terms of gender, there is a slightly higher preference for the top activities among females. Undergraduate students emphasise the importance of skill development through software usage, competition participation, and internships. [17]

These learning techniques prioritise practical implementation of knowledge rather than pure theory, fostering student engagement and challenging them to find sustainable solutions. However, it is important to acknowledge the need for a theoretical background in understanding the topic.

By combining these techniques, students can learn to analyse the bigger picture, recognize environmental limits and finite resources, understand the impact of engineering projects on communities, and more. Therefore, a **key recommendation** is to carefully plan courses and approach the learning process at universities, striking a balance between theory and practice, and providing opportunities to address real problems. Lastly, it is important to recognize that ESD should not only develop skills and competencies but also contribute to lifelong learning and initiate a shift in everyday behaviour and attitudes towards a more sustainable world.

3.4. Embedding sustainability in the curriculum

The need for education about the environment and sustainable development has been recognized since the Stockholm conference in 1972. Over the years, extensive discussions have taken place regarding the integration of sustainable development into academic curricula. However, there is now a growing interest in developing and integrating sustainable development into curricula at all academic levels (Lozano F.J, Lozano R., 2013, pp. 136-146).

Higher Engineering Education, with its strong traditions, faces the challenge of transitioning to more innovative curricula based on active and cooperative learning. Embracing this challenge is essential to enhance EESD.

Sustainability is currently addressed in various ways within Higher Education. Examples shared during the focus group include:

- Standalone modules dedicated to making processes, such as manufacturing, more environmentally friendly;
- Specific courses on sustainability and sustainable technologies, offered as either compulsory or elective subjects;
- Projects focused on the SDGs and related issues.

The effectiveness of these approaches depends on several factors, including the competencies and interest of teachers/lecturers in sustainable development, the structure of courses, and the overall mindset and awareness of sustainable development topics in different countries, cultures, and universities.

In the field of EESD, three key pedagogical approaches are commonly employed: learner-centred pedagogy, action-oriented learning, and transformative learning (UNESCO, 2017, pp. 54-56).

Embedding sustainability within the curriculum can be challenging, but there are several **recommendations** to consider. The curriculum should aim to develop students' sustainability literacy and foster the development of sustainable skills. This can be achieved by incorporating diverse activities, such as project works with real-world implementation and direct links to the SDGs. Additionally, promoting extracurricular activities outside of the university that contribute to sustainable skills development is beneficial. Higher Education institutions should also provide support for educators to enhance their sustainability knowledge and education, and work towards creating an overall sustainable-oriented environment.

4. SUMMARY

As we reach the halfway point of the implementation period for the SDGs, there is still a need to determine how education should be adapted to effectively address the significant economic, social, and environmental challenges we face. The examination of the current state of EESD reveals variations between nations in their strategies and level of commitment towards addressing sustainability concerns.

While the data gathered and analysed in this research is limited and cannot be generalised on a larger scale, the insights provided align with previous studies conducted. The **key takeaways** on accelerating sustainable literacy for behaviour change and collective action are as follows:

1. Higher Education institutions should reshape the curriculum to contribute to the development of sustainable skills and foster a more sustainable mindset;
2. The activities included in the curriculum should support the practical implementation of the knowledge;
3. Educators, Higher Education institutions, industry and governments must commit to creating interdisciplinary action-oriented curricula;
4. Higher Education institutions should provide support to educators in implementing innovative teaching methods;
5. Students need to continue advocating for the necessary changes, and hold decision makers accountable.

In conclusion, the process of identifying all the essential and critical areas for sustainable education is complex and extensive. Therefore, there is an urgent need for the academic community to respond in an agile manner. Rather than seeking the perfect solution through extensive benchmarking, it is crucial to take action towards a more sustainable future. While curriculum adjustments may seem tempting to address educational deficiencies, the issue extends beyond curricular coverage. It also involves curriculum implementation and the design of effective learning environments.

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Taking curriculum reform to the next level: the need for decolonising work in engineering education

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Conference Key Areas: *Embedding Sustainability and Ethics in the Curriculum, Engagement with Society and Local Communities*
Keywords: *Decolonising, Discourse, Ethnography, Ethics, Society*

ABSTRACT

As humanity is faced with unparalleled challenges, from the climate emergency to rising inequality, there is a renewed emphasis on the role of engineering professionals to contribute solutions to global problems. However, there is increasing recognition that the way that engineers are trained through higher education is inadequate to prepare them to address these grand challenges. This paper aims to deepen theoretical perspectives on why the engineering education status quo is falling short. Taking a British perspective, I outline how the epistemology and cultural ideologies, or the "episteme," of engineering continues to shape our discourses within modern day engineering education, and constrain our ways of knowing, thinking, being, and acting. I will present data from a critical ethnography to reveal how discourses of engineering continue to be steeped in coloniality and perpetuate Western, modernist narratives for the need for growth and technologically-driven development. I aim to demonstrate that approaches to curricular reform will continue to fall short without concerted efforts to decolonise our ways of knowing and doing in engineering. Finally, I provide some suggestions on pathways forward.

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1 INTRODUCTION

1.1 The engineering status quo

Engineers have been responsible for the development of some of the most consequential and widespread technological innovations in human history (Amadei 2014; Downey 2014). From water sanitation systems to refrigeration to mobile phones to trains and cars and airplanes, the vast impacts of engineers on the world in which we live are undeniable. As we as a society are faced with unparalleled challenges, from the climate emergency to rising inequality to Western political destabilization, there is a renewed emphasis on the role of engineering professionals to contribute solutions to global problems.

However, it is crucial to recognize that engineering innovations and interventions have not necessarily always led to positive or beneficial change for all (Clemence 2020). High profile engineering disasters - from the Bhopal disaster to the Grenfell tower fire – are some of the more obvious indicators of a disconnectedness between engineering and society. Yet, while these high-profile examples may increase the public salience of the precarity of engineering products and structures, it is the less obvious examples that shed light on the more insidious and subverted nature of engineers' lack of connectedness to broader social accountability. Bugliarello (1991) offers the following provocation:

> "Would the societal consequences have been different if engineers had been more involved in a systematic study of engineering's complex role in society, had a working dialogue with social scientists, and had better communication with the public? For instance, could we have anticipated that the automobile would turn out to be a severe source of pollution as well as a powerful instrument of urban change [or] that radios in every household would catalyse the political emancipation of women…?" (74).

Answering these questions requires nuanced, multi-level political, ethical, and social conversations which involve engineers. However, "the voice of engineers in the discussion of engineering's social role has been weak, episodical, and often self-centred" (Bugliarello 1991).

1.2 Cultural formation of engineers

As the previous examples demonstrate, the ways in which engineers view themselves in relation to the wider world, and the ways in which they act and apply their engineering knowledge are not neutral or consequence free. Then how is it we have a profession like engineering that is so vital to us as a society, yet consistently misunderstands or eschews crucial aspects of its social responsibility?

Engineering, like other professions, is not just a collection of knowledge, skills, and practices grouped into a set of jobs. Professions have rich and historically rooted cultures that are built into and around their knowledge, skills, and practices" (Cech and Sherick 2015). Using Foucault's concept of episteme, the following exploration delves into the historical foundations of modern-day engineering in the UK. According to Foucault, an episteme "delimits in the totality of experience a field of knowledge, defines the mode of being of the objects that appear in that field, provides man's everyday perception with theoretical powers, and defines the conditions in which he can sustain a discourse about things that is recognized to be true" (Foucault 1970). Bevir (1999) suggests that "although epistemes are rarely held consciously, they exercise an all-pervasive influence, saturating all of the religious, philosophical, scientific, social, and artistic thought and practice of an age" (Bevir 1999). Said in another way, an episteme is a culturally and historically constructed boundary condition that frames knowledge and understanding of the world. In his later work on "genealogy," Foucault incorporates the concept of power in his analysis of knowledge formation. Genealogical analysis aims, in part, to uncover the way that power relations form and are perpetuated through history by illuminating their role in serving specific social agendas (Foucault 1980).

If we acknowledge that the formation of engineering culture occurred through a historical trajectory and served particular social agendas, then it is important to spend some time understanding critical moments in the formation of modern engineering culture. Downey and Lucena suggest that "the identity of the engineer" emerged during the Enlightenment period (Downey and Lucena 2005). The episteme of the British engineer, therefore, must be understood through the lens of this historical period.

In the United Kingdom, the Enlightenment period intersects with British imperialism and colonisation. In fact, the Enlightenment ideal of progress was fuel for empire building. This particular notion of progress was undergirded by positivism, a philosophic position which emerged during the Enlightenment era in Europe, as a move to "cleanse men's minds of mysticism, superstition, and other forms of pseudo-knowledge" (Schön 1983). Positivism rests on the assumption that there is an objective truth, and it is possible to uncover that truth through the theory and methods of science (Denzin and Lincoln 2008).

British imperialism highly valued technical knowledge, quantitative data, and positivistic ways of knowing, putting engineers at the centre of social and political goals of the age. A brief history of this context is provided in the following section.

1.3 Engineering and capitalist colonial expansion

Throughout the 18th and 19th centuries, a new form of imperialism was on the rise, in the form of Western capitalist colonial expansion. Colonisation is defined by Loomba (2002) as the "conquest and control of other people's land and goods" (2). The process of colonisation has meant "unforming or re-forming" existing communities by colonizers, using a wide range of practices, including "trade, plunder, negotiation, warfare, genocide, enslavement and rebellions" (Loomba 2002). European empires were not the first to expand imperial might or establish colonies abroad. But the form of imperial expansion advanced by European powers, including the United Kingdom, was distinct. "Never before had one civilization overwhelmed all the others and set them on an entirely new course" (Headrick 1988, 4).

“Modern colonialism did more than extract tribute, goods and wealth from the countries that it conquered - it re-structured the economies of the latter…so that there was a flow of human and natural resources between colonised and colonial countries” (Loomba 2002, 3). One aspect of “re-structuring” new colonies involved transforming non-capitalist economies into those that could be exploited by European capitalistic interests. “This allows us to understand modern European colonialism ...as an integral part of capitalist development” (Loomba 2002, 20).

The “physical and material dimensions” of this new form of imperial expansion were advanced through the vehicle of engineering and technological innovation. Engineers were heavily involved in the construction of colonial infrastructure that facilitated extraction (Lucena 2015). Technological innovation and invention, such as steamships, and improvements in firearms and railways, increased the speed and efficiency, and decreased the cost, of colonial expansion into African and Asian territories. Technology was developed by Western engineers and scientists, for the benefit of the West, and “with scant regard for their long-range impact on the tropics.” (Headrick 1988, 7).

It was through their labour that engineers served the interests of imperial governments in building out their empires. By helping to “permanently transform” the structure of life in colonies throughout this time, engineers, whether consciously or not, participated and became complicit in the rise of capitalist colonialism (Loomba 2002; Lucena, Schneider, and Leydens 2010; Lucena and Schneider 2008).

This relationship is not over. It has been argued that the historic alignment between engineering, colonisation and capitalistic interests has not radically changed since the colonial age (Conlon 2019; Lucena, Schneider, and Leydens 2010; Slaton 2015). Some attest that that the colonial era never really ended, it just evolved into new forms of extraction and dehumanization, with engineers continuing to play a pivotal role in these systems (Boisselle 2016; Dei and Kempf 2006; Smith 1999).

The case of sea defence infrastructure in Guyana is a modern example illustrating the persistent effects of an entrenched colonial regime. Mullenite (2019; 2018) critically examined the social and political ramifications of colonial and postcolonial flood remediation projects in Guyana through genealogical analysis. During the colonial era, British colonialists infiltrated and gained increasing control over daily life through the construction and management of sea defence infrastructure. This strategy was extended by the postcolonial Guyanese regime, using “infrastructural commitments to maintain and grow their economic and political power” (Mullenite 2018, 187). Though the British regime formally ended in 1966, it is only recently that the Guyanese have begun reviving nature-based, indigenous sea defence solutions, such as regrowth of mangrove forests (175). This work highlights how a technological approach to flood management embedded a capitalist, colonial politic, an approach that has persisted into the present day.

2 METHODOLOGY

2.1 Methods

Escobar argues that “we need to anthropologize the West” (Rabinow, 1986, as cited in Escobar 2011, 11). This paper forms some contributions to that project. Results and discussion are drawn from a larger critical ethnography of an engineering department within a British HEI, with field work taking place in 2018-2019. The broader study focused on the first year of a new engineering MSc programme in engineering management for sustainable international development. Primary data collection methods involved participant observation, ethnographic and semi-structured interviewing, and reflexive journaling. Key informants/participants involved staff and students involved with the course, as well as key community partners involved with student projects. All key participants gave their informed consent. Any names mentioned in the analysis are pseudonyms.

2.2 Analysing discourses

In the following paper, I focus my analysis on discourse. In ethnography, identifying discourses through observed language acts serves as an important way of uncovering symbolic meaning. However, the degree to which ethnographers use and analyse discourses varies. In critical ethnography, this work can serve an important function in helping draw connections between micro-level empirical data and macro-level social and cultural conditions (Carspecken 2013; Davies 2012).

Discourse is a social process related to the way we use language. It is more than the exchange of content in a conversation, or the grammatical systems of syntax and morphology that make up common language. Rather, understanding language use as discourse acknowledges the impact that language has in shaping our world. Discourse allows us to know things, “to do things” and “to be things” (Gee 2004). Fairclough (1992) describes discourse as “a practice not just of representing the world, but of signifying the world, constituting and constructing the world in meaning” (64).

Foucault is credited with showing how discourse analysis can be used to deepen our understanding of the mechanisms of power in society. Foucauldian discourse analysis has become a critical tool for studying coloniality.

> “Discourse analysis...makes it possible to trace connections between the visible and the hidden, the dominant and the marginalised, ideas and institutions. It allows us to see how power works through language, literature, culture and the institutions which regulate our daily lives” (Loomba 2002, 47).

In the current study, there were many incidences throughout my fieldwork where I observed uses of terminology that appeared to uphold colonising representations of relations between British and sub-Saharan African nations. In the following sections, I connect ethnographic observations of language acts and with established theory on colonial discourses to draw some tentative conclusions about the ways in which participants contributed to the reproduction of colonial relations. I draw on Escobar’s analysis of development “as a regime of representation” that has established and maintained Western conceptions of developed vs. developing and First vs. Third World (Escobar 2011). I aim to highlight how “stereotypes, images, and ‘knowledge’ of colonial subjects and cultures tie in with institutions of economic, administrative...control” (Loomba 2002, 54). I do so by drawing connections between the structure and content of the MSc course, the ways in which students, staff, and community partners relate to one another, and the discourses of development and coloniality.

3 COLONIAL LANGUAGE ACTS OBSERVED

3.1 Supremacy of imperialistic capitalism through development discourses

The terms “sustainable development” and “international development” have become commonplace across Western higher education institutions. Their inclusion in the names of courses of study, volunteer abroad excursions, and student societies signal opportunities for students to “do good” and to “help.” Alexander (Alexander 2012) contends, however, that terms like sustainable development have become “potent but empty rallying cr[ies], laden with positive value but so variable in content that [they are] almost devoid of meaning, other than being a Good Thing.” In an engineering context, these terms, especially sustainability and sustainable development, have come to mean something about the environment, but rarely connect to issues of society. Taken further, by applying an anti-colonial lens, we can start to see that “sustainable” or “international development” may not just be innocuous “good things,” but may have more insidious, colonial roots.

In Encountering Development, Arturo Escobar applied discourse analysis to the concept of “development” within the context of colonisation. In his analysis, he demonstrates how “development has relied exclusively on one knowledge system, namely, the modern Western one” (13). Escobar shows how “the dominance of this knowledge system has dictated the marginalization and disqualification of non-Western knowledge systems” (13).

Most telling of how the concept of “development” is used as a tool for maintaining colonial power relations is the story of how the term has been applied in the post war era. Though the concept of development is not new, the way that “sustainable development” and “international development” are used today emerged in the mid-1900s. During this time, a group of “so-called modern states (primarily Western European [countries] and the United States, and later Canada and Japan) created institutions (such as the International Development Association and UNESCO)” and convened panels of “experts” to “learn about, support, and improve life…in so-called developing states” (Kendall, 2009). An effect of this process was the construction of a new underclass of people in newly independent nations of the global south – “the poor” (Escobar 2011; Kendall 2009). Prior to this, the poverty of “natives” was not a great concern of colonizing nations. The general belief was that “even if the ‘natives’ could be somewhat enlightened by the presence of the colonizer, not much could be done about their poverty because their economic development was pointless. The natives’ capacity for science and technology, the basis for economic progress was seen as nil” (Escobar, 2011, 22).

The change in the Western conception of poverty “occurred…first with the emergence of capitalism in Europe and subsequently with the advent of development in the Third World.” The invention of Third World poverty came the notion that “the poor” were “a social problem requiring new ways of intervention in society” (Escobar, 2011, p. 22). This new social problem required mechanisms and indicators of progress, which have been set by Western development institutions, and have largely focused on economic measures, such as Gross Domestic Product (GDP) per capita, job creation and growth, and access to modern technology, such as hospitals or electricity (Kendall 2009).

Though there have been many challenges to this econo-centric position, none have been powerful enough to shift the discourse of development beyond it or consider what alternative indicators of human progress could be. “The relative stability of the term ‘development’ reflects continued general agreement amongst powerful actors and institutions around the world on the shape and scope of the international development arena” (Kendall, 2009, 420).

Western higher education institutions are embedded within these global power relations and are part of the mechanisms that reproduce them. It was during the formation of institutions like UNESCO that concerns about the development of the Global South became salient to the field of education. UNESCO itself took up the mantle of education for development with the organisation of regional education meetings. There was a concurrent rise in other education-related professional bodies and institutions, including the US-based Comparative Education Society (Kendall, 2009). Over the past 70 years since, Western institutions of higher education took up the mantle of researching and developing pedagogy focusing on the “problem” of “the poor” in the “Third World.”

Engineers have also been involved in development interventions since the inception of Western development institutions. Naturally, the transfer of technology, a key component of colonial and neo-colonial strategy and discourses, has relied on engineers’ involvement. However, from the colonial to the neo-colonial era, ideologies around “natives’” need for science and technology morphed. From the belief that Africans were devoid of scientific thinking and technology, emerged the creation of the concept of the “Third World” and the necessity of its development. “In 1948, a well-known UN official expressed this … in the following way: ‘I still think that human progress depends on the development and application of the greatest possible extent of scientific research. . . . The development of a country depends primarily on a material factor: first, the knowledge, and then the exploitation of all its natural resources’” (Escobar, 2011, 35).

Though engineers have been involved in the practices and discourses of development for centuries, “they never scaled up to make inroads in ...engineering education or in the mainstream professional conduct of engineers until [recently]”

(Schneider et al., 2009, 44). This shift has occurred, in part, as engineering interventions in the "Third World" focused on providing technical assistance and "appropriate technologies" to "communities" (44). "Engineering to Help" initiatives have made an appearance in Western higher education institutions, through organisations like Engineers Without Borders and Engineers for a Sustainable World (Schneider, Lucena, and Leydens 2009). There has been a concurrent increase in the number of programmes and courses of study in engineering higher education institutions.

3.2 Development discourses identified within the MSc course

There were a number of development discourses identified within the larger study of the engineering management for sustainable international development MSc. For the purposes of this paper, I will focus on two examples: discourses identified within taught modules, and within students' conceptions of their work.

Community Engagement was one taught module within the MSc, delivered by an external educational partner. The module aims of Community Development were articulated to the students as follows:

> **Module Aims:** In the last 50 years community groups have demanded and increasingly been offered an important role in planning and designing new developments and large scale engineering projects. Today, in an environment of localism and nimbyism, with local residents increasingly seen as 'experts' in their own right, community engagement has become a crucial part of any development process. The module will introduce the role and importance of engaging communities, teaching various techniques of consultation and engagement, placed in a framework from top-down to bottom-up. These techniques will be placed against a range of critiques of engagement that have emerged in recent years, from the accusation that engagement silences, co-opts or manipulates local people. The module will include evolving examples of engagement such as the 'charrette', 'Enquiry by Design' and others, and will include a practical project in which students take part in engagement exercises.

In this descriptor, there is the implication of asymmetrical power relations between "community groups" and an invisible narrator. If community groups have been demanding and increasingly offered a role in planning and designing new engineering projects, who have they been demanding this from? We can infer the invisible narrator may be someone who has traditionally held power over the entire process of development. This person or group likely is from the West and has expertise in engineering. By situating this invisible narrator in the context of a module descriptor, students reading this text can easily step into the shoes of the invisible narrator, becoming the expert who holds the reins of power, controlling the nature and extent of engagement with "local people." The lecturers who represent those who have been in power to decide on the course of development on behalf of "community groups" for centuries, are once again reinforcing these power relations, and training a new generation to take up their mantel.

Another module, Introduction to Development Studies, establishes the social and political context that the students would be working within. During one of the module sessions, I noticed that the conversation was rooted within Western discourses of development. The British and European staff and students on the course seemed very comfortable within this discourse and dominated the conversations.

> *Back in Anders' Monday lecture. I noticed this the last time I was here, too, but the way that Anders and some of the white, European students talk about SSA [sub-Saharan Africa] and other developing nations is very "othering." Not only do they dominate the dialogue in the classroom (frequency of weighing in), they talk about these nations as "developing," in terms of poverty, in terms of evaluative statistics* (observation, October 22, 2018).

There were students from the "developing world" sitting in the room and I noticed that these students were quieter in the context of this conversation. It may have been because those students came from an engineering background and were not as familiar with the content. Some of the European students and staff were engineers, and they seemed to have no hesitation to weigh in. It may have also had to do with different school cultures. In the West, students are encouraged to participate in discussion from early ages, whereas in other parts of the world, there is more of a hierarchical structure, where students are taught to listen to the teacher. I wondered at the time if the differences in their participation had more to do with the nature of the conversation, being dominated by Western thinking and the marginalizing way they spoke about "the developing world."

> *… there are people from around the world, including Africa and South Asia in this room. I wonder how the various students in the room feel about the nature of the conversation about Africa, poor/developing nations, poverty, etc* (observation, October 22, 2018).

Western development teaching and interventions appear to hinge on the process of stakeholder engagement, as if, by "engaging with stakeholders" or "engaging with community," Western outsiders can help to surface or determine "needs" and then deliver "solutions."

During another social science module, students learn about social research methods to support their field work. Figure 1 is from a lecture in the module, depicting a project cycle for "systematic rapid assessment."

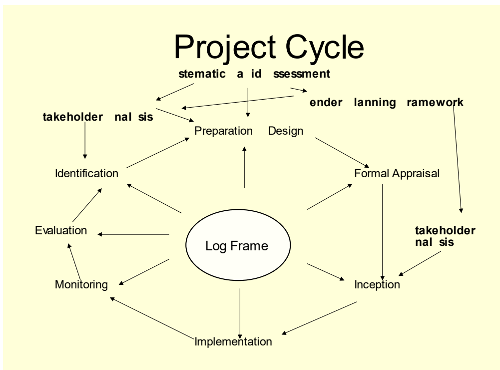

Fig 1. Slide from MSc module

Though the class where this project cycle was taught involved considerations of "participation," the framing of participatory methods still seemed to rely on an outside "researcher" who assesses the lives and "issues" faced by a community/stakeholder group. The researcher takes the lead in collecting and analysing information and formulating an intervention. The assumption within this module was that participation can open “up the possibility of involvement in planning and management of development projects and programmes” (observation, December 2018).

These various influences helped create the conditions where references to the “developing world” and the “Third World” were commonplace and acceptable. The way that development was framed in modules popped up throughout the year and was parroted by students. During a group meeting between students and staff to discuss final dissertation projects, one student made generalisations about “really high numbers of people” in the “developing world” and their approaches to cooking. This related to his technical dissertation, which was focused on a community-based model of cook stove technology.

> Luke: …really high numbers of people in the developing world still cooking off open fires and simple stoves and obviously this contributes to a lot of premature deaths and respiratory-based illnesses, mainly. … we’ve known this a long time, and there’s been lots of interventions that have looked at sustainable cooking solutions. Like … clean cookstoves is massive, you have community cooker…There's a number of reasons why these aren’t as wide spread as it could be and I think, to give an example of one, it’s gender dynamics, because you know, it's the women who cook, but it's the men who hold the money quite often and then they don't want to invest in a better stove for their wife to cook or what have you… So … there's lots of stuff already happening. But it's quite slow in this field because of those gender dynamics, because that market doesn't exist and … I think the power thing’s really interesting because, like what Biolight, that company with the stove is doing …they're looking at where you can use the waste heat to generate electricity. Well this is really interesting…we'd like to see gender mainstreaming, and we’d like to progress towards this, but now you've given a reason why the man now wants to upgrade his wife’s stove, because now he can charge his phone on it. So, he has an incentive to go and buy a better, more efficient stove...

I was struck by the way that Luke, a British student, discussed the “developing world” and issues of gender relations within it. He spoke in generalities about how men and women divide labour and spending, across the developing world, failing to differentiate between national, tribal and/or ethnic identities in cooking preferences or habits, or gender relations. He seemed confident in the Western development approach that Western-developed cookstove technologies could help bring “progress.” His assuredness and righteousness gave the impression of his authority over the path of development of others: “we’ve known this a long time” and “of course, we’d like to see gender mainstreaming.” The “we” in his statements seems to refer to him and people like him – white, Western holders of superior knowledge of how development should occur.

4 CONCLUSIONS

This paper aimed to demonstrate how the episteme of modern engineering, formed through forces of Western imperialistic and racialised colonialism, continues to act upon our discourses within modern day engineering education.

In this paper, examples from an ethnographic study of an MSc in engineering management for sustainable international development were provided to demonstrate the ways in which students, staff, and their external stakeholders reproduced coloniality. The course reinforced modern conceptions of development, which, though challenged and critiqued, have not significantly changed since their inception.

This is not for lack of good ideas or intentions. It is, in large part, because we still exist within coloniality – a totalising force on our modern world. This includes the pervasive modern discourses of progress and development and the ways in which they form and are formed by the structure of our neo-colonial capitalist economy.

Engineering, as a vehicle of colonial supremacy, became intimately intertwined with these discourses and structures. And the way that engineers are trained has not escaped these factors.

Decolonising efforts are making strides toward addressing the inequities and injustices that emerged out of colonialism. The episteme of engineering makes the work of decolonisation even more critical and potentially even more challenging, given the historical, cultural, epistemic, and structural roots of engineering and how closely intertwined they are with imperialistic capitalistic interests. Yet as educators, the purveyors of knowledge and professional socialisation, is this not part of our collective responsibility?

If we are to engage in decolonising work, we must start with careful examination of ourselves and the ways in which we may reproduce systems of oppression. This will require challenging positivistic ways of knowing and doing in engineering practice and education. As discussed in the introduction, what is considered valuable knowledge in engineering education and EER is still shaped by positivism, the philosophic position that fuelled imperialistic colonialism.

Critically reflective practice, or praxis, can help to uncover new understandings of history and power relations in engineering education. Paolo Freire's conceptualisation of a liberative pedagogy provides us solid ground upon which to open ourselves to alternative ways of being and knowing. It can help us open ourselves up to alternative philosophical standpoints from which to re-shape our ethical frames, as well as problem definition and problem solving in engineering. Ecological models, indigenous ways of being and knowing, and other subsistence forms of living may provide inspiration. Many of these models and frameworks exist outside of engineering education research – the decolonising work ahead requires the importation of these approaches into our knowledge and practice.

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EXPERT-NOVICE DIFFERENCES IN ELECTRICAL CIRCUIT ANALYSIS BASED ON THE ORDER OF ATTENTION

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Conference Key Areas: *Engineering Skills and Competences, Lifelong Learning for a more sustainable world, Fostering Engineering Education Research*
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ABSTRACT

The difference between experts and novices during problem-solving has been established in several domains. However, in electrical engineering, studies are

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sparse. This study compares experts and novices in an introductory electrical engineering course. Four novices (students) and three experts (teachers) were made to solve eight circuit problems with a concurrent think-aloud protocol conducted remotely due to COVID restrictions in India at the time of the study. Experts predominantly followed the direction of the current showing a working-forward strategy. Conversely, Novices displayed a means-end approach by jumping to mathematical calculations more than anything else. In addition, the arrangement of complex circuits confused them as they tried to solve the circuits based on a superficial understanding of the problems. We discuss the results in the context of what is already known about expert-novice differences.

1 INTRODUCTION

Polya's problem-solving approach in 1945 (Ersoy 2016) comprises four fundamental stages: comprehension, formulation of a solution approach, implementation of strategies, and evaluation of the solution. Experts generally engage in all four aspects, while novices only use the latter stages. Research has revealed that individuals with well-organised domain-specific knowledge exhibit superior problem-solving abilities. In contrast, inexperienced individuals tend to employ surface-level frameworks and possess rudimentary domain knowledge. Experts possess a variety of problem-solving strategies and are capable of formulating precise plans before the actual execution of the solutions. They have a restricted repertoire of problem-solving strategies and rely heavily on explicit problem information while being susceptible to irrelevant information.

Psychologists and educational researchers have spent much time studying the characteristics of experts and novices in various fields, from science and engineering to chess and music. Previous studies in such disciplines have uncovered problem solvers' behaviour during problem-solving. One such study observed that experts emphasised all the significant stages of bacterial growth and the meiosis process in their illustrations of chromosome meiosis (Kindfield 1994). Experts in music composition employed a strategic approach that involved prior planning and a vast repertoire of procedures that flexibly considered various solutions and ultimately selected the most appropriate one (Colley et al. 1992). Novices rely on surface-level information when investigating genetic problems (Hardiman, Dufresne, and Mestre 1989), pay attention to structural aspects of energy and force problems, and prioritise visual appeal when engaging in geological structure sketching tasks (Jee et al. 2013). Experts also employ more heuristics and place a higher value on the availability of comprehensive information within design briefs (Björklund 2013; Dixon and Bucknor 2019).

Circuit diagrams represent an electrical circuit that uses symbols to represent electrical and electronic devices, such as resistors, capacitors, transistors, and switches. In electrical engineering courses, circuit diagram problems are often used to teach students about circuit analysis and design.

Some common types of circuit diagram problems include:

1. Finding the total resistance of a circuit: Given a circuit diagram with resistors in parallel or series, students may be asked to calculate the circuit's total resistance.
2. Calculating current and voltage: Students may be asked to calculate the current or voltage at different points in a circuit, given the circuit diagram and basic information about the circuit.
3. Circuit analysis: Students may be asked to analyse a circuit diagram to determine how different circuit components interact and how changing one circuit element affects the overall performance.
4. Circuit design: Students may be asked to design a circuit that meets certain specifications, such as a specific voltage or current output, using the knowledge they have gained from analysing circuit diagrams.

Overall, circuit diagram problems are an essential part of electrical engineering courses, as they help students develop a deep understanding of how electrical and electronic devices work and how they can be used to design complex systems. This study aims to examine the disparities between experts and novices in electrical engineering as it is a field and area from which we still need data. We seek to answer two interrelated research questions.

RQ1:- What discernible distinctions are between experts and novices in their approach to solving electrical circuit diagrams?

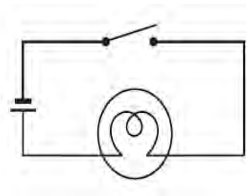
RQ2:- How do the findings of this study align with the information presented in the literature on expert-novice comparisons?

2 METHODOLOGY

Three experts and four novices participated in this study. For this study, novices were students in their second year of an electrical engineering degree course at an engineering college in Maharashtra, India. The students successfully fulfilled the requirements of the "Basics of Electrical Engineering (BEE)" course in their first year. The experts had a sound understanding of the course material, were knowledgeable about the BEE course requirements, and held the academic rank of assistant professor with a master's degree in electrical engineering.

The initial plan was to conduct an eye-tracking study with the group. However, due to pandemic restrictions, we were forced to conduct a concurrent think-aloud protocol with remotely located participants. The study's participants were instructed over a video call to solve electrical circuits while concurrently verbalising their cognitive processes. A set of eight electrical circuit diagrams, each progressively more challenging than the last, were selected from the BEE course textbook followed in the college.

The first two circuits assessed fundamental knowledge of circuitry, as they feature uncomplicated components such as resistance, bulb, switch, and power source (Fig. 1.1 and 1.2). The next three circuits were interconnected through a combination of resistance in series and parallel configurations to satisfy Kirchoff's laws governing current and voltage (Fig. 1.3, 1.4, and 1.5). These circuits are moderately difficult. Finally, the last three circuits include advanced electronic components, such as diodes, transistors, and thyristors and were designed to investigate higher levels of concept mastery (Fig. 1.6 to 1.8).



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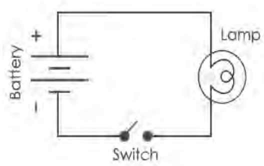

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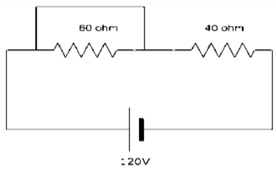

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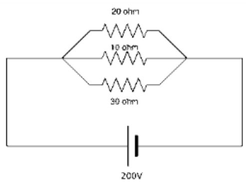

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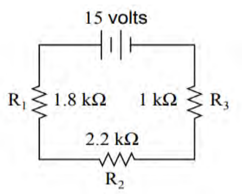

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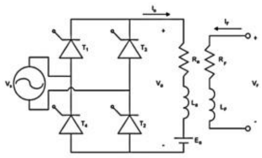

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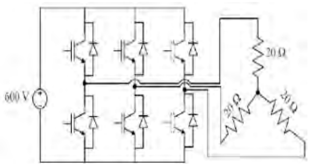

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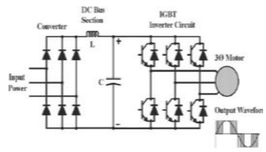

1.8

Fig. 1. Basic Electrical Circuits from the electrical engineering curriculum

Following the presentation of diagrams to the participants, we documented their progress through remote observation on a video call. The subjects were asked to verbalise which components they looked at as they solved the problem. The researcher later processed this concurrent think-aloud data to create annotations on the circuit diagrams to mark their order of attention on the elements during the problem-solving process. Following the completion of problem-solving tasks, retrospective interviews were administered to participants to ascertain the rationales underlying their selection of components, paths, and strategies during the process of circuit solution. Each of the interviews above lasted approximately 10 to 15 minutes.

3 RESULTS

All eight circuits were analysed for the study. However, we will restrict our discussion to circuits in Fig. 1.1, 1.3, 1.5 and 1.6, as they were both representative and more interpretable. For the circuit shown in Fig 1.1, the novices directed their attention towards the switch (Sw), subsequently shifting their focus towards the bulb (Bu) and ultimately towards the source (Ba) (Fig. 2.(left)). The experts analysing the circuit focused on Ba initially, followed by Bu, and subsequently shifted their attention to Sw. However, their analysis did not conclude there, as they ultimately returned to the Ba to complete their solution (Fig. 2 (right)). The logic behind starting with the battery, as revealed in a later interview (excerpt below), was to discern the source of the current and the elements were visited in that order only.

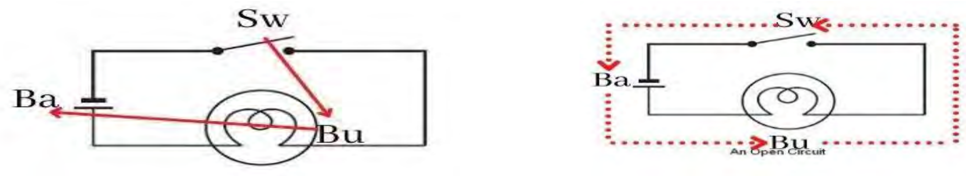

Fig. 2: Novice‘s (left) and expert‘s (right) order of attention for circuit 1. The straight arrows indicate attention to elements such as switch, bulb and battery. The dotted line indicates attention to elements based on the direction of the current.

Expert-1 :

“...The search for current in the circuit began by examining the battery terminals to determine the direction of current flow. The direction of the current was then followed through each element of the circuit….”

Expert-2 :

“...When observing the current flow, it can be observed that it originates from the source and subsequently interacts with other electrical components before ultimately returning to the source to complete the circuit loop….”

The excerpts above provide valuable insights into experts' methodology in circuit analysis. These experts prioritise the direction of the current as a crucial factor in their approach to circuit problem-solving. Specifically, their initial step involves identifying the current's origin point and proceeding in that direction. This approach is further reinforced by the experts' adherence to the "Source-Load-Source" pattern,

Expert-3 :

"...I am not concerned more about the load but the source. Slight modulation in a circuit can lead to bigger changes in the application, so the source is more important to me….”

In contrast, novices showcased a generalised “Load to source” order of attention,

Novice-1 :

"...The determination of the response is contingent upon the load value. The load component is an integral aspect of any circuit, and the calculation of other components is dependent on the knowledge of the load value…."

The reasoning underlying the statement made by Novice-2 is:

"...The significance of load in circuit analysis lies in its ability to serve as a reference point for selecting the appropriate mathematical equation to solve the circuit…."

In circuits of greater complexity, such as Circuit 3 and Circuit 4 depicted in Fig. 3, the bulb is substituted with one or multiple resistors. Nevertheless, the observed pattern for such circuits remains consistent with simple circuits.

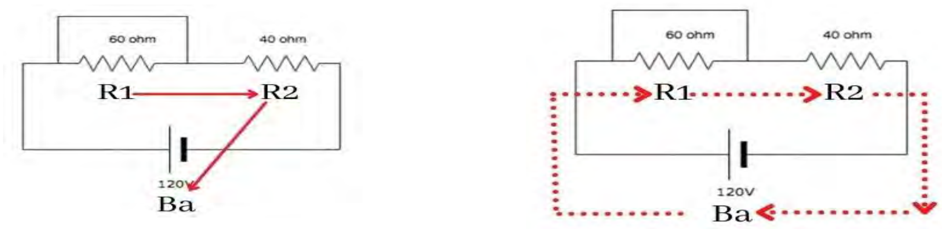

Fig. 3:- Novice's (left) and expert's (right) order of attention for circuit 3. The straight arrows indicate a focus on elements such as battery and resistances. The dotted line indicates attention to elements based on the direction of the current.

In Circuit 5, novice participants exhibited a random pattern as depicted in Fig. 4 (left) and (middle). Conversely, experts stuck to the pattern established in simple circuits, starting from the source and following the current. (Fig. 4 (right)).

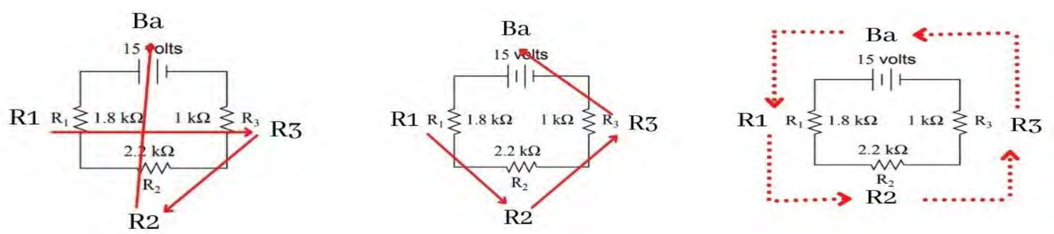

Fig 4.:- Novice's (left and middle) and expert's (right) order of attention for circuit 5. The straight arrows indicate a focus on elements such as battery and resistances. The dotted line indicates attention to elements based on the direction of the current.

Furthermore, the reasoning behind Fig. 4. (left) and (middle) was explicated by the novice as follows,

For the pattern in Fig. 4 (left), Novice 1 said :

"... I thought R1 and R3 are parallel to each other; that's why I saw them one after the other…".

However, for Fig. 4*(middle)'s* attention sequence, Novice 3 explicated :

“...All three resistances are in a series configuration. After looking at R1, I was looking for R2 so my natural instinct was R1, R2 and R3…”

In Circuit 6, the original battery was substituted with an alternating current (AC) source, and the basic linear loads, such as resistors and bulbs, were replaced with DC series motors (RLE represents the electrical equivalent circuit of a DC series motor). Additionally, a new current/voltage controller, such as a thyristor, is introduced. The novices showed order similar to easy and medium circuits. Experts, however, showed two distinct orders in this case.

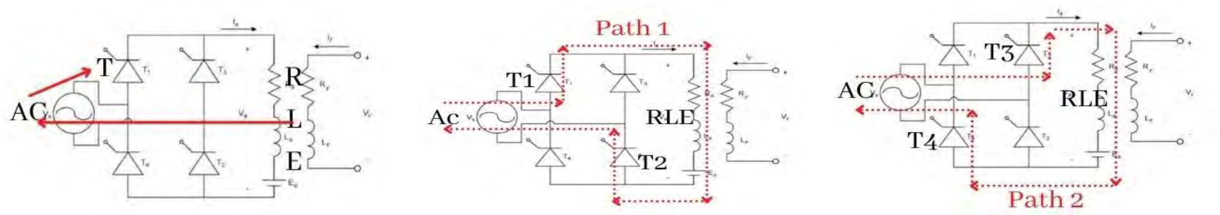

Fig. 5.:- Novice‘s (left) and expert‘s (middle and right) order of attention for circuit 6. The straight arrows focus on elements such as AC source, RLE load and Thyristors. The dotted line indicates attention to elements based on the direction of the current.

They have taken path 1 for positive half cycles, where voltage controller Thyristor 1 and Thyristor 2 are triggered (Fig.5 (middle)). Similarly, they have taken path 2 for negative half cycles, where controller thyristors T3 and T4 are triggered (Fig.5(right)).

4 DISCUSSION

We discovered two significant differences between experts and novices in this study. First, novices should have paid more attention to the source and concentrated more on the load side of the problem. In contrast, experts focussed on the direction of the current and visited the elements in that order, regardless of the complexity of the circuit. The focus on the load side of the problem by novices can be attributed to finding a solution to the question posed. This goal-oriented behaviour indicates the use of a means-end approach, wherein problem solvers concentrate on achieving the final goal of the problem by taking incremental steps and utilising various mathematical operators (Larkin et al. 1980; Sweller 1988). Some researchers have also referred to this behaviour as the "backward inference technique" (BIT), wherein novices identify what is being asked and work backwards until they find the information outlined in the problem (Rosengrant et al. 2009). In the context of a circuit, this was evident from the lack of attention to the current direction.

In contrast, experts predominantly base their approach on this fundamental concept in circuit diagrams, as reflected in their "source to load" order of attention. The direction of the current flow plays a crucial role in the solution process of experts, while novices tend to overlook this aspect. Experts displayed a working-forward method, in which they first infer critical intermediate solutions from the data provided to them, then delve into the principles required to solve the problem, and finally focus on the mathematical or analytical solution (Chi, Feltovich, and Glaser 1981; Larkin et al. 1980; Day 2002; Tabatabai and Shore 2005). This is often termed the "forward inference technique" (Rosengrant et al. 2009).

Second, novices' attention to elements was guided by superficial knowledge and/or problem representation, whereas core concepts guide experts. This difference is likely to give more variance in novices' order of attention than those of experts. For example, in Fig 4 (left), novices could make the incorrect supposition of R1 being parallel to R3 (superficial knowledge) or that R1, R2 and R3 need to be looked at in that order (superficial problem representation) in Fig 4 (right). This finding closely resembles the observations made by Fredette and Clement (1981) in their study. They discovered that students tend to depict the circuit elements as parallel in the circuit representation, even though they are in a series combination on the physical equivalent.

Conversely, experts follow the same pattern as they did for simpler circuits: follow the current, revealing an underlying dependence on core concepts and less reliance on external problem representation. Notably, the difference in expert order of attention for circuit 6, both path 1 and path 2, was not because of superficial knowledge or representational reasons but because of alternating current, again a key concept.

One way to reduce the observed expertise gap is to make the problem-solving of experts visible to novices. There may be more viable solutions for this purpose than explaining attention through concurrent think-aloud. However, eye-tracking technology may be used to illustrate an expert's way of solving a circuit problem. An eye movement modelling example or EMMEs, where novices look at the gaze patterns of experts that help them focus on the expert's problem-solving techniques, could be one way to do that. (Xie et al. 2021; Krebs, Schüler, and Scheiter 2019; Jarodzka et al. 2012)

5 LIMITATION

Despite the expected findings being congruent with literature from other domains, this study is limited because of its small sample size. Furthermore, looking at stimuli, comprehending them, and verbalising thoughts might have imposed an additional cognitive load on participants, and their thoughts may not reflect what was said.

This study was conducted during the pandemic using a concurrent think-aloud protocol, which is the strength of this study as it provides a roadmap for future studies in electrical engineering education that needs to be conducted remotely. However, this approach lacked precise control over the cognitive strategies employed by participants. To overcome this limitation, we propose to use an eye tracker of suitable frequency (>60 Hz) to record the order of attention of participants.

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CIVIL AND ARCHITECTURAL ENGINEERING STUDENTS' CONCEPTUALISATION OF GOOD ENGINEERING AND ITS IMPLICATIONS FOR ETHICS EDUCATION

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Conference Key Areas: *Embedding Sustainability and Ethics in the Curriculum; Built Environment and Architecture Education*
Keywords: *ethics; culture; civil engineering; architectural engineering*

ABSTRACT

The ways in which students conceptualise what it means to do good engineering illuminates their values and priorities and shapes their understanding of ethics in engineering. The present study is part of a larger project that is exploring civil and architectural engineering students' understanding of ethical and societal responsibility and its development via formal and informal learning. Data collection and analysis are ongoing in the larger project, and the present study focuses on eight semi-structured interviews with civil and architectural engineering students at one university in Belgium. The analysis was designed to address how civil and architectural students conceptualise good engineering and the potential role of the engineering culture in this meaning-making. The data were examined through the lens of Cech's culture of disengagement: a framing for how engineers conceptualise their professional responsibility and understand what it means to be an engineer. The findings include good engineering has a human-centred purpose, is responsible, and requires interpersonal competencies, all of which diverge from the tenets of the culture of disengagement. However, in alignment with the framework, there is evidence that students perceived gatekeeping in their programme to determine who

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can do good engineering. The implications raise awareness around the culture of engineering and point to students' interest in using it for community benefit.

1 INTRODUCTION

1.1 Background

There are many arguments for the integration of ethical and societal issues in engineering education. From accreditation to industry pressure to societal expectation, ethics is considered an important part of “good engineering.” However, what constitutes good engineering can be ambiguous. For example, “a good engineer is an engineer who cares about doing good engineering” (Davis 2015, 5). These broad ideals about good engineering can be especially challenging for students to interpret with limited engineering-related work experience. The values and norms around what constitute good engineering are culturally constructed and therefore turning an eye to culture can indicate what good engineering means and how students come to internalize it.

1.2 Theoretical Framework

Undergraduate education is a period of socialization through the processes of adapting to the engineering culture, assuming the identity, and showing unity with others (Dryburgh 1999). The culture of engineering thus informs the ways of knowing and being that students are formally and informally learning. Culture describes a group’s values and beliefs (Schein 1996), which in the context of this study, can explain how “good engineering” is conceptualised.

The present study is framed in the culture of disengagement (Cech 2014) to explore the inter-relationship between definitions of good engineering and their implications for engineering ethics education. The culture of disengagement is a set of practices and beliefs that inform engineers’ understanding of their responsibility to the public, and it has epistemic implications for how engineers value knowledge. Cech (2014) used longitudinal data from engineering students at four universities in the United States (US) to understand students’ public welfare beliefs and how they changed over time, the extent to which the programme culture emphasizes public welfare, and whether the programme emphasis related to students’ beliefs. This worked concluded that “engineering education fosters a culture of disengagement that defines public welfare concerns as tangential to what it means to practice engineering” (45). The culture of disengagement is propped up with three pillars. (1) Depoliticization frames “non-technical” as irrelevant, and a potential bias, to real engineering. (2) Technical-social dualism separates social considerations and privileges the technical. (3) Meritocratic ideology indicates that existing social structures are fair and just, and those who do not succeed deserve their outcome. The culture of disengagement contributes to engineering students leaving their programme less committed to public welfare than when they began: it underpins an understanding of good engineering as being technical, meritocratic, and unbiased from social and political dimensions.

1.3 Research Question

The research is guided by the following question: how do undergraduate civil and architectural engineering students conceptualise good engineering?

2 METHODOLOGY

2.1 Project Context

The present study is part of a larger project that is exploring undergraduate civil and architectural engineering students' conceptualisation of ethical and societal responsibility (Polmear 2022). The larger project includes semi-structured interviews with civil and architectural engineering students at one university in Belgium and one in the United Kingdom (UK) to explore students' understanding of the impact of engineering and the responsibility of engineers, including experiences inside and outside the classroom that shape it. As part of a constructivist grounded theory approach (Charmaz 2014), data collection and analysis are ongoing in parallel to develop emergent theory. The present study focuses on the interviews conducted in Belgium.

2.2 Data Collection

This study employed semi-structured interviews and took a cross-sectional approach to include participants at every level of their Bachelor's studies in civil and architectural engineering. Participants were recruited through an email the faculty, emails to professors in the programme, and visits to the design studio to speak to students. Through these processes, eight students scheduled and completed interviews in April and May 2022, and their information is provided in Table 1. The research was approved by the Ethics Committee for Human Science.

Table 1. Participant Information

Pseudonym	Year in Programme	Gender
Anna	2	Woman
Brigitta	2	Woman
Hann	2	Woman
Henriette	2	Woman
Joris	2	Man
Naomi	3	Woman
William	1	Man
Wallorroo	2	Woman

The following questions, as part of a broader scoped interview, were designed to understand students' ideas around good engineering. The questions were contextualized in their own journey and career plan to make the responses more specific to their experience, rather than about engineering in general.

- Can you describe your journey into (civil or architectural) engineering?
- Looking to after graduation, what are you hoping to do in your career?
- In the context of (their career interest), how would you describe good engineering?

- Can you give an example of what you consider good engineering?

2.3 Data Analysis

The first step in the analysis was generating complete transcripts from the audio recordings using an online service. I then verified the accuracy and removed identifying information. I conducted the data analysis in Dedoose, a web-based qualitative and mixed-methods analysis platform. The thematic coding following multiple cycles (Saldaña 2013). The first cycle was deductive with the codes informed by the three pillars of the culture of disengagement: (1) depoliticization, (2) technical-social dualism, and (3) meritocratic ideology. Recognizing that much of the data fell outside of these codes, the next steps was inductive coding to capture the emergent student conceptualisations of good engineering. The final cycle of coding was thematically grouping the data within each code to identify salient patterns. Through this cycle, I identified four themes that address how civil and architectural engineering students make meaning of good engineering through the framing of the culture of (dis)engagement.

2.4 Positionality

I recognize my positionality, which is constructed through my identity and perspective, impacts the research process and warrants transparency (Secules et al. 2021). I conducted the interviews and analysis, and the ways in which I engaged with the students and interpreted the data were influenced by my position inside and outside the research context. My academic training in civil engineering helped me understand the culture and curriculum and establish common ground with the students. However, my understanding of the broader culture and education system in Belgium was more limited since I was not born nor education there. Throughout the interviews, the students and I worked together to establish common understanding. For example, if they were not able to find a word in English (all were native Dutch speakers) or I was not familiar with the name of an organisation or programme on campus, we would take care to explain.

2.5 Limitations

One consideration in interpreting the findings is that data collection was not designed with the analytical framework in mind. The framework was employed *ex post facto* to understand students' conceptualisations of good engineering within a broader conversation around ethical and societal responsibility. It is also worth noting Cech's framing was developed and tested in the US context. Despite the globalisation of the engineering workforce, distinct engineering cultures exist in different countries. For example, the types of knowledge and jobs that are valued in France, Germany, the UK, and the US are different (Downey and Lucena 2005).

Another consideration is the data were collected at a single moment in time. The quantitative data in Cech's study were longitudinal and showed the decline over time of students' public welfare commitments. Future work could take a longitudinal and qualitative approach in the Belgian context.

3 FINDINGS

The findings are presented in four themes with representative participant quotes to address the research question.

3.1 Good engineering has a human-centred purpose

When asked to consider what defines good engineering, three students shared the perspective of it being human-centred and purpose-driven. As an example, Hann stated:

> *That's good engineering because you don't need a lot of steel to make this thing. Or you can think good engineering as in this building, this thing has a purpose, it's doing something good for people. I think that's both equally as important kind of. But I do tend to focus on the human aspect. Yeah, I think a good example of what I don't want to do is what they do in Dubai, those giant skyscrapers to show prestige. I would not feel good if that was what I would do in a few years.*

Hann went on to contrast skyscrapers in Dubai to the types of projects she wanted to work on as an engineer: affordable housing to address the current housing crisis. Henriette similarly defined good engineering in terms of an example of a professor who designs temporary shelters for people to use during humanitarian crises, like the war in Ukraine, and said “that’s someone who inspires me.”

William also shared that good engineering addresses “Who do I want to give it to? What do they need? Is it really the right place to place it there?” He provided the example of a course project for which he spoke with the community for whom he was designing the building. Through these conversations, William learned the community members wanted a clean space to talk and sit, so his design prioritized those features. Across these examples, good engineering meant addressing people’s challenges and being attentive to their needs. It is also important to note that students’ interest in using engineering to help others increased during their programme. When asked about their initial motivation to study engineering, none of the students mentioned pro-social commitments. The most common response was an interest in combining math and creativity. It was only upon entering the programme that students gained this perspective of what good engineering can do, such as Brigitta who said, “It was after I started that actually realized, ‘Okay, this is what engineer can do.’"

3.2 Good engineering is responsible

For two of the students, good engineering meant being responsible. As an example, Anna shared

> *Good engineering, I think, an engineer has a lot of responsibilities. Take the example of a bridge. If there's something wrong in a little calculation, the bridge could fall, and the engineers behind it are at fault.*

Her comment reflected the importance of technical responsibility (the “calculation”), responsibility to safety (the bridge falling), and responsibility in terms of “fault.” Joris also understood good engineering as a responsibility, which he explained as,

> *I think, first of all, good engineering means that you didn't forget anything or anyone. Something I've learned is that engineers have a lot of things to worry about… You have to think about so many things, not only about how it looks and if it would break down or not, you also just have a certain responsibility and that's something we've learned especially in the second semester of this year, that engineers really have a certain responsibility with them.*

For Joris, responsibility meant being holistic and inclusive in your approach. Students were asked later in the interview about responsibility in engineering, but these responses above were shared before I mentioned “responsibility.”

3.3 Good engineering requires interpersonal skills

A third theme I developed from the codes was the importance of interpersonal, social skills to good engineering. As an example, Anna shared

> *A good engineer also has to be creative, I think, because we have to have a problem-solving mind. That's very important, I think. I think we have to be also good at working together because we can't do everything alone. I think that's a very important part of engineering, is co-working and good communication.*

Her comment reflects creativity, problem-solving, teamwork, and communication as facets of good engineering. Naomi similarly emphasized teamwork,

> *Good engineering, I think working in a group is a very important thing, because it's not one person that has to do all the calculation. But it's like a group thing.*

These interpretations of good engineering speak to the creative, collaborative nature of engineering practice that requires skills in communicating and working with others.

3.4 Gatekeeping who can do good engineering

Thematic analysis of the codes related to meritocracy indicated gatekeeping in engineering education that determines who can enter and continue in the programme. For Joris, this gatekeeping starts before the programme as he explained,

> *Well in order to even start with this course you have to do something called the [name of exam], it's basically a test where they evaluate how much you already know about mathematics, chemistry and physics. And based on that grade you kind of have an idea if you are smart enough to complete.*

Joris’ comment alludes to the meritocratic structures of the system that use an exam to determine who is “smart enough” to do an engineering degree. For Naomi, this evaluation of who belonged continued throughout the programme.

> *I won’t say it has been as easy journey… The profs do have an opinion of your work, and it's kind of subjective. Also with the design studio, so I also in my*

second year, I had to stop at design studio, because I was so […] The profs were so hard on me. And last week, I had a conversation with a girl, and she said to me, 'Yeah, five people stopped with design studio, and a couple of people stopped with the study because of the professors'… but a lot of people also go through that. And they stop, and they can't handle with it, so stopping is the only thing they could think of.

Naomi dropped out of the programme during her second year (and later returned) because she struggled with how the professors treated her, in particular the harsh and seemingly subjective feedback she received in the design courses. Naomi's experience, which was shared with other classmates, speaks to the culture of engineering education that serves as gatekeeping for what constitutes good engineering and who can stay in the programme long enough to do it.

4 DISCUSSION

This research explored civil and architectural engineering students' understanding of good engineering through a qualitative approach. The analysis was framed in the culture of disengagement (Cech 2014) to examine the interplay between good engineering and public welfare reasonability. Through thematic coding of semi-structured interviews, I identified four themes related to students' conceptualisations of good engineering. These themes are situated in the analytical framework and existing literature to develop implications for engineering ethics education.

The first theme, good engineering has a human-centred purpose, marks a difference from the culture of disengagement. Students' priority of addressing human needs does not align with the culture of disengagement pillar of depoliticization in which social and political considerations are disconnected from "real" (i.e., good) engineering. Students wanted to use engineering to address politically and socially fraught challenges, like housing and humanitarian crises, rather than bracket those concerns, and this interest increased through the programme. In Cech's work, on the other hand, students' commitment to public welfare declined over time. This divergence warrants future research to understand the longitudinal nature of students' perspective in the Belgian context. An implication of this finding is the power of the engineering programme in cultivating, not diminishing, these commitments to public welfare. Students cited examples from their courses where they learned about engineering being used to address social challenges that were attentive to people's needs. Such examples, whether the focus of a project or a brief mention, can carry weight for how students understand good engineering and engineering for good.

Another point of departure between the data and framework relates to the third theme: good engineering requires interpersonal skills. This perspective does not align with the culture of disengagement pillar of technical/social dualism that separates and devalues social competencies. Although a few students noted the importance of problem-solving, none of them conceptualised good engineering in terms of technical mastery but rather emphasized creativity, communication, and collaboration. Although the broader discourse in engineering education reflects the implicit, and sometimes explicit, devaluing of professional and social competencies (Berdanier 2022), students in the present study acknowledged their importance. One implication of this finding is for engineering educators to continue emphasizing professional competencies, integrating them in technical courses, and providing opportunities for students to develop them.

Lastly, there was evidence of meritocracy in the data in terms of structures (and individuals) that determine who is allowed in and through the programme and can thus do good engineering. Gatekeeping has long been acknowledged as an issue in engineering (Main, Johnson, and Wang 2021)(Weston 2022) while concerns around engineering culture and student mental health have grown recently (Jensen and Cross 2021). Understanding the implicit and explicit ways that students are told whether they belong in engineering has important implications for individual students and education as a whole. Future work can continue to explore meritocratic norms in related to good engineering and ethics education.

5 SUMMARY

This research explores civil and architectural engineering students' understanding of good engineering and its interplay with the culture of disengagement and ethics education. The findings include good engineering has a human-centred purpose, is responsible, and requires interpersonal competencies, all of which diverge from the tenets of the culture of disengagement. However, in alignment with the framework, there is evidence students perceived gatekeeping in their programme to determine who could do good engineering. The implications raise awareness around the culture of engineering and point to students' interest in using engineering for good.

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EXPERIENCES AND LEARNING OUTCOMES OF USING VIRTUAL REALITY IN BUILDING SERVICES ENGINEERING EDUCATION

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ABSTRACT

Virtual Reality (VR) is a promising learning environment in vocational and higher education as it enables learning by doing. We developed a digital twin (DT) for learning the most common maintenance procedures of an air-to-water heat pump using game engine technology, targeted for students and professionals in the building services engineering industry. 22 HVAC (heating, ventilation and air conditioning) students participated in a user study to evaluate their experience with the DT, their usage preferences, and learning outcomes. Results of an online post-test questionnaire show that participants found the use of the DT easy and useful for learning maintenance procedures, regardless of their previous experience with VR devices or video gaming. More than half of the participants reported preferring to use the DT before practicing with the physical device. Learning outcomes measured with eight questions indicate that most of the students learned the tasks and safety issues correctly and in correct order (72-95% answered correctly). However, the questions measuring the learning related to adjusting the pressure was challenging for almost all students. The functional and task correspondence as well as the visual similarity of the digital twin to the real-world context is important for learning outcomes. The reported perceived usefulness by students for using VR in learning the maintenance procedures was related to realism of working with the digital twin, illustrating the maintenance procedures and tasks, as well as safety issues in the learning phase. The transfer of learning to real maintenance situations could be tested on the physical device.

1 INTRODUCTION

1.1 Background

Virtual reality (VR) systems are gaining increasing interest in training of maintenance and service tasks. In vocational training and in life long learning, experiential learning (Kolb and Kolb, 2005) is a commonly used educational approach in training of maintenance workers (Borsci et al. 2016). The goal of utilizing virtual reality in maintenance training is to achieve an immersive, realistic experience (ibid.). Students can perform tasks and various procedures in virtual, simulated environments that include virtualized physical equipment and systems (ibid.). These virtual counterparts of real equipment are called Digital Twins (Grieves and Vickers, 2017; Jones et al. 2021; Semeraro et al., 2021).

One of the mentioned advantages of using virtual reality in maintenance training is the efficient transfer of knowledge to the real environment (Guo et al., 2020). Also improvement of maintenance personnel safety is highlighted, as VR enables the learning of maintenance procedures and processes before conducting them on site (ibid.). The use of virtual reality in the training, practice, and certification testing of complex and dangerous maintenance procedures, such as high-voltage power line maintenance, has been shown to be a cost-effective tool for training new employees (Ayala García et al., 2016). The number of practice sessions in virtual reality can also be greater than in the real world, and learning procedural skills, which often involve sequential steps as in maintenance procedures, can be effective when implemented in virtual reality (Bailey et al. 2017).

However, the results on transfer of learning may not be similar in all training contexts. In the meta-analysis of XR (extended reality) studies from multiple fields on transfer of training, Kaplan et al. (2021) found that extended XR was as effective as commonly accepted training methods. The most commonly mentioned value of XR is described to be training in circumstances, which are hard to access or dangerous, or where the cost of training may be too high in traditional environment (ibid., Vasarainen et al. 2021).

In recent studies, the effect of the information presentation format during the learning phase on personal workload and task performance has been examined. Shi et al. (2020a) compare the learning of operating instructions for performing pipeline maintenance in an industrial environment using four different methods. They compare two different 2D functional instructions to 3D and VR implementations. The 3D and VR implementation groups performed better on the task than groups who received either of 2D functional instructions, but experienced higher cognitive workload during the memorization phase. Borsci et al. (2016) found that training for car service maintenance with VR/MR resulted in a lower number of unsolved errors and training time compared to traditional training. In addition, the trainees' experienced VR/MR tools to increase the understanding of tasks and procedures.

1.2 Goals of the research

The goal of this research was to examine whether VR is useful as a learning environment in training maintenance tasks in vocational training from the point of students as well as learning outcomes. To this end, we evaluate in a user study the user experience, students' usage preferences, and learning outcomes of using a Digital Twin (DT) of an air-to-water heat pump (AWHP). With DT we here refer to a virtual representation of a real-life system, that uses a game engine to create a realistic high-quality representation of a system. The implemented enables to learn and carry out two of the most important and common tasks and procedures to maintain an AWHP.

There are a number of definitions for DTs (see e.g. Jones et al. 2021; Semeraro et al. 2021). The most typical parts of a DT are the 1) physical products in real-world, 2) their virtual counterparts in VR, and 3) their connections through data and information transfer (Grieves and Vickers 2017). In addition to being used in training of maintenance procedures, DTs can be used as part of more advanced maintenance strategies. Currently, predictive maintenance dominates, but in the future condition-based maintenance and in preventive maintenance are of interest (Errandonea et al. 2020). These advancements have also been taken into account in the competence goals of vocational training, where working in digital environments has been added as a learning goal (Paananen et al. 2023, 6-7). The development of the DT in this work aims to support these new competence goals to give experiences of new digital environments.

2 LEARNING OBJECTIVES AND IMPLEMENTATION OF THE DT

The digital twin of an AWHP was developed in collaboration with the heat pump manufacturer. The goal of creating the DT was to provide training and learning opportunities for common maintenance. The maintenance tasks selected for implementation were pressure adjustment and relief valve testing, cleaning of the strainer, and room cleaning, which were identified as the most common causes of maintenance downtime and were deemed maintainable not only by domain experts, but also by technically competent heat pump owners.

The DT was created using Unity game engine to model the outdoor water source heat pump images in a VR (virtual reality) environment. The game engine enables the creation of realistic 3D environments that can be designed to work with different VR headsets and controllers. Building the VR environment fully customized using Unity tools enabled the creation of an independent end product that can be easily adapted to different usage situations without the need for different licensing terms or fees associated with pre-made commercial VR learning solutions and platforms.

Unity is a popular platform for other VR implementations due to its ease of developing VR headset functionality and its cheap and well-documented platform (Checa and Bustillo. pp. 5509-5510, p. 5519, 2020). An interactive, but linear, process-oriented VR implementation was aimed for as realistic and reality-based interactive implementations have been found to be effective in virtual reality implementations compared to either passive and more affordable models without interactions (ibid., 2020). They are, however, more cost-effective compared to freely exploratory and interactive environments, which are more expensive and time-consuming to develop (ibid., p. 5519).

The use of the DT in a VR environment was designed to support a procedural learning experience that progresses step-by-step according to the maintenance procedure. The DT guides the user with text instructions at each step and explains what to do next. Progress from one step to another requires correct completion of the task steps in the correct order to unlock the next task.

3 METHODOLOGY

3.1 Procedure of the user study

The user study was conducted with HVAC (heating, ventilation and air conditioning) students. Testing was arranged during normal lessons based on voluntary participation. The students came to the test session to the classroom where the used system was set up and used the DT for learning the maintenance tasks. 1-2 researchers were present during the test. Participants were explained the test procedure, informed about the possibility to withdraw from the study at any time, and to inform the researchers immediately if feeling nauseous when using the DT. Researchers guided the participants on how to use the VR system prior to starting the use of DT. In case a participant had problems in progressing in the tasks during the test session, researchers helped the student by giving instructions. In the end of the test session, students answered an online post-test questionnaire with a computer.

3.2 System

The computer used in the test had an Intel Core i5-7500 processor, Intel UHD Graphics 620 and NVIDIA GeForce RTX 2080 TI graphics card, and 16 GB of memory. In the test situation, the VR headset used was the HTC VIVE Cosmos, along with its controllers. One Vive base station was used to track the movement of the controllers and the headset. The application being tested was the digital twin of the AWHP device. The pedagogical approach for learning the maintenance tasks and procedures utilized procedural learning approach.

Figure 1. Test session setup in classroom

3.3 Participants

22 HVAC students participated the user study. All of the participants were men (age m = 16, min 15, max 21). 77% of the participants were first year students, 18% second year students, and the rest (5%) third year students. Participation to testing and answering the questionnaire was voluntary.

Most of the participants (86%) had no prior experience of AWHP maintenance. The rest had some prior experience. 41% of the particpants had no prior experience of using VR systems and 41% had little prior experience. Most of the participants (91%) had at least some experience in video games (computer, gaming consol or mobile games).

3.4 Post-test questionnaire on user experience, usage preference and assessing learning outcomes

The online questionnaire was created using Microsoft Forms. The questionnaire aimed to gather students' experiences using the digital twin for learning maintenance procedures, as well as their preferences for using digital twins in education. Additionally, the questionnaire measured learning outcomes by asking questions related to the maintenance tasks and procedures they practiced with the DT. At the end of the questionnaire, three open-ended questions were asked to gather further development ideas and students’ perception of the usefulness of the DT.

Seven questions gathered information on the participants’ background, including prior experience on digital gaming and using VR applications as well as on prior experience on AWHP maintenance. User experience was assessed with three statements on a five-point scale (see Table 1). Three questions covered 1) student’s concentration during learning of maintenance procedures on the VR device or AWHP (immersion supported by ease of use, adapted from Gavish et al., 2015), 2) ease of use of the digital twin (adapted from Gavish et al. 2015 Tepsa et al. 2022,), and 3) usefulness of the digital twin in learning (Tepsa et al. 2022). Furthermore, preference was asked for learning and practicing maintenance procedures for the AWHP using the DT or the physical device (Table 2).

Learning outcomes were assessed with seven questions covering the tasks and procedures practiced with the implemented DT (Table 3). Multiple-choice questions allowed for selecting multiple answers. For six questions there was only one correct answer. For the question 7, "What do you check in AWHP pressure adjustment?", there were two possible correct answers. All multiple-choice questions also had an option "I don't know".

The eighth question to assess the learning outcomes by using the DT was measured by asking to organize the maintenance procedures in correct order. The question on the correct order of the maintenance tasks had multiple correct orders of tasks, as in real life. Only orders that posed a safety risk - such as disconnecting the mudfilter before turning off the water supply, which would cause water damage - or were logically impossible were considered incorrect when checking the results. For example, pressure cannot be increased without opening the indoor unit front panel. Another example of a hazardous situation would be not closing the valve leading to the outdoor unit before removing the mud filter, as this would cause water to rush out and cause water damage. Also, leaving the valve open after cleaning the mud filter is considered a mistake because the equipment will not function properly. Leaving the main power on before maintenance work was also considered an error, as this could cause a hazardous situation, as well as leaving the main power off after maintenance. An example of a logical error is that it would be impossible to check the pressure adjustment of the internal unit if the front panel had not been opened before the maintenance tasks.

4 RESULTS

4.1 User experience and usage preference

The user experience was measured using four questions. The questions, scales, mean, and standard deviation of answers to three first questions are reported in Table 1.

Table 1. User experience of the Digital Twin

Item	Question	Scale	mean	std
1	Did you focus more on using the VR system or learning the maintenance tasks of AWHP? (N = 22)	1 = Mainly on using the VR system 3 = Equally to using the VR system and learning the maintenance of the AWHP 5 = Mainly on learning the maintenance tasks	3.7	1.20
2	How easy it was to use the digital twin? (N = 22)	1 = Extremely difficult 5 = Exremely easy	4.4	0.60
3	How useful did you find the use of the digital twin in learning the maintenance tasks? (N = 21)	1 = Not useful at all 5 = Extremely useful	4.1	0.65

Most participants reported focusing more on learning the maintenance procedures of the AWHP than using the VR device (Table 1). However, some participants reported that they focused more on the VR device than on learning the maintenance procedures with the DT. About one-third of the participants reported focusing equally on using the VR device and practicing the AWHP maintenance procedures. Focusing more on the VR device usage than on the content and learning is unpreferable. This could be reduced by either including in the test procedure or the VR implementation a learning phase for usage of the devices and controls prior to the learning phase of the maintenance procedures.

The use of the digital twin was perceived easy by most participants (95%), and none found it difficult to use. Most participants (86%) also found the use of the digital twin useful in learning the AWHP maintenance procedures. We also investigated by cross-tabulating whether there is a correlation between prior video game experience or prior experience using VR devices and the perception of usefulness and ease of use. Neither prior video game experience nor prior experience of using VR devices had significant effect on the perceived usefulness and ease of use.

Additionally, participants were asked about their preference for using the digital twin or the physical device in practicing the AWHP maintenance procedures (Table 2). More than half (59%) of the participants preferred using the digital twin first for learning and then continuing the learning with the physical device. 14% of participants would only use the digital twin in learning the maintenance tasks, while 18% of the participants would prefer to use only the physical device in learning.

Table 2. Preference of DT or physical device in learning and practicing

Preference	% of answers
First digital twin and then physical device	59%
Digital twin	14%
Physical device	18%
I don’t know	9%

4.2 Assessment of learning outcomes

Table 3 summarizes the learning outcomes measured with the multiple choice questions. Learning outcomes are at least somewhat satisfactory for 5/7 questions, varying from 72% to 95% correct answers.

Table 3. Learning outcomes based on multiple choice questions

Item	Question	Correct answer	I don’t know
5	What do you do before carrying out the maintenance tasks?	73%	5%
6	How do you adjust the pressure of an AWHP on the physical device?	14%	73%
7	What do you check when adjusting the AWHP pressure?	9%	
8	What do you do before removing the mud filter**?**	82%	5%
9	What do you do to the mud filter after removing it?	95%	5%
10	Why is it important to keep the space around the AWHP clean?	77%	5%
11	What do you do after succesfully completing the AWHP maintenance?	72%	14%

However, the two questions (6 and 7, see Table 3) related to pressure adjustment were difficult for the participants.The reason for confusion can be that the digital twin had two separate extra buttons for adjusting the pressure and the color of these extra buttons was not consistent with the color of the real buttons (see Figure 1). Therefore the implementation of the DT was different from the physical model in this respect. Reason for this difference was that the buttons were in a tight space inside the heat pump model, close to each other. With the used VR controllers, such situations cause difficulties in control because the controller selects the adjustable object based on the hand position. In future implementations, in case similar controllers are used in interaction, the color coding of these buttons to adjust the pressure should follow the colors in the actual device or strong zooming into the actual buttons should be enbled to remove the need for separate buttons. The learning outcome in this task shows that such interface design solutions have a significant impact on the transfer of learning to the real world. In design of DTs, it is essential to ensure that the student's mental model corresponds to the actual implementation of the physical device.

Figure 2. Implementation of the UI for pressure control

In the question asking for ordering of maintenance tasks, 73% of participants ordered the maintenance tasks in the right order. 14% of participants made one error, either logical or causing a hazardous situation, but otherwise ordering the tasks correctly. 9% of participants ordered some of the tasks in correct order. One participant ordered the tasks randomly.

4.3 Perceptions on usefulness

An open-ended question about the usefulness of the digital twin was included for collecting qualitative feedback from the participants. The responses were thematically analyzed. Three themes related to perceived usefulness were identified: realism, illustration, and work safety (see Table 3).

Table 4. Emerging themes in answers related to the usefulness of learning in VR

Categories of themes	Examples of coded descriptions	Frequency of mentions
Realism	A situation corresponding to a real maintenance situation A sense of agency in performing maintenance	5
Illustration	Illustrates the sequence of maintenance operations Illustrates the functionality of the system	4
Work safety	Shows where there are safety risks Provides an opportunity to practice operating procedures without safety risk	2

The most often mentioned theme related to usefulness was realism. Respondents mentioned similarities between learning with a digital twin and a physical device. In addition, maintaining the DT was felt to be similar to maintainance of the physical system. One of the participants described the experience as "able to practice like in real life". The second most often mentioned theme was illustration. Respondents described the DT as illustrating the system quite realistically and illustrating the maintenance work beforehand. Practicing the maintenance with DT was described to help both in understanding the system's operating principle as well as in understanding the maintenance procedure sequence and its precise execution. Work safety emerged as the third theme raised by the respondents. DT was mentioned to help in identifying and learning about work safety risks. One participant highlighted the feeling of safety for the student in the learning situation: "you can practice system maintenance without any physical harm."

5 SUMMARY

In this study we examined the user experience and learning outcomes of using a digital twin (DT) for learning the two most important maintenance tasks of an air-to-water heat pump. The participants assessed the DT easy to use and useful for learning. Over half of them preferred first using DT and then the real system for learning the maintenance tasks. The amount of prior experience of video gaming or using VR solutions did not have a significant effect on the perceived ease of use and usefulness of the DT. Realism of performing the maintenance, illustration of the functionality and maintenance operations, as well as safe operation in learning phase and learning about safety risks were mentioned by participants to contribute to the perceived usefulness. Learning outcomes were measured with a post-test online questionnaire. Learning was on satisfactory level, except for a task where the physical device and the implemented DT were not consistent with each other due to interaction related challenges. This highlights the importance of realism of the digital counterpart compared with the physical system. To measure the transfer of learning to real world from training with a DT, instead of the online questionnaire a test on a real device could be conducted to test the learning of the maintenance procedures.

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Quantitative Analysis of China's Application-oriented Talents Cultivation Policies

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ABSTRACT

Faced with a new wave of scientific and technological revolution and industrial transformation, the Chinese government has implemented policies to cultivate application-oriented talents. Application-oriented talents utilise engineering theories and technical methods to achieve engineering objectives. Cultivating such talents

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enables Chinese engineering education to meet better the needs of local economic and social development, promoting the differentiated development of Chinese higher education. We use quantitative methods to analyse China's application-oriented talents cultivation policies. The analysis focuses on the changes in policy contents and characteristics of policy responses to capture the developmental trends and critical stages of these policies. Findings from our study indicate that China's policies and measures are more and more specific according to the practical demands. There has been a shift in emphasis from scale expansion to quality improvement in application-oriented talents cultivation. The evolution of these policies follows a path-dependent pattern with gradual changes over time. Most provinces have actively responded to the Chinese central government's policies. However, there is a specific time lag in their responses. The number of response policies formulated by a single policymaker is higher than those formulated jointly by multi-policymakers. Our study can provide educators and policymakers with a clearer understanding of the critical focuses and characteristics of cultivating application-oriented talents and references for formulating and implementing engineering talent cultivation.

1 INTRODUCTION

1.1 Research Background

Given the current inadequacy of China's talent-cultivating structure and quality to meet the demands of economic structural adjustment and industrial upgrading (Ma 2023), along with the pressing issue of prominent structural contradictions and severe homogenisation tendency in higher education, as well as the need to promote the classified development and management of higher education, theoretical research on the cultivation of application-oriented talents in China has long been discussed in the academic community. Furthermore, the Chinese government has also extensively explored policy formulation and implementation.

Based on the positioning of talent cultivation, Chinese higher education can be broadly classified into three main types: research-oriented, application-oriented, and skill-oriented. Application-oriented talents primarily utilise engineering theories and technical methods to achieve engineering objectives (Xia and Yi 2016). Specialised higher education institutions in many countries have been established specifically to cultivate such talents (Schüll 2018; Lepori and Kyvik 2010; Teuscher 2019). Notably, the distinguishing feature between application-oriented and research-oriented talents lies in their practical engineering skills (Yuan and Zheng 2002). Application-oriented talents, closely related to practical engineering and societal issues, are integral to China's engineering talent pool. The cultivation of application-oriented talents also addresses the long-standing scientific-oriented cultivating model in Chinese engineering education (Luo et al.2008). It ensures a better alignment between talents nurtured by higher education institutions and industry job requirements, thus enabling engineering education to meet better the practical needs of local economic and social development and promoting social and academic integration (Tarazona and Rosenbusch 2019).

Existing research papers primarily explore the connotation (Wu and Huang 2014), historical origins (Pan and Shi 2009), case studies (Zhuang and Zhou 2004), and evaluation systems (Wu 2006) of application-oriented talents in China. However, there needs to be more quantitative analysis concerning relevant policies. Furthermore, research has not been found regarding provincial-level governments' responses to the central government's policies on this topic. Policies fundamentally reflect governments' social management endeavours (Huang 2016). Quantitative analysis and computation of policies offer valuable insights into their characteristics, current status, and temporal changes. Analysing the policies for cultivating application-oriented talents in China provides a deeper insight into the dynamic policy objectives and thematic changes in higher engineering education. Moreover, it allows us to comprehend the shift in the government's governing philosophy and the implementation and diffusion of the central government's policies at the provincial level, offering valuable references for cultivating engineering talents and higher engineering education in China and globally.

1.2 Research Questions

The research questions addressed in this study are as follows:

1) How have the application-oriented talents cultivation policies the Chinese central government issued evolved?
2) What is the response of provincial-level governments to the central government's policies for cultivating application-oriented talents?

To address these questions, we systematically utilise policy text analysis and quantitative methods of policy literature to examine the application-oriented talents cultivation policies in China. It analyses the current status and changes in the policies issued by the central government and the responses of provincial-level governments. The study aims to gain insights into policy development trends and critical stages, providing valuable references for policy design and research on developing application-oriented talents cultivation.

It is worth noting that although China has expanded the scale of application-oriented talents by cultivating professional degree postgraduates (which differ from academic degrees, such as Master of Engineering and Doctor of Engineering), most application-oriented talents in China are still undergraduate students. Therefore, this study focuses on analysing the policies for cultivating undergraduate-level application-oriented talents.

1.3 Data Sources

The data sources for this study include application-oriented talents cultivation policies at both the Chinese central and provincial levels, which have authority.

The policy text data for this study are obtained from the following sources, with the policy retrieval cutoff date being May 2023:

1) The primary source of policy texts was the "Peking University Law Information Retrieval System" (http://www.pkulaw.cn), China's most authoritative legal information retrieval system. The policy texts are retrieved using the keyword "application-oriented," and irrelevant policies unrelated to application-oriented talents cultivation or the construction of application-oriented universities were excluded. The full text of the policies is downloaded to form the foundational dataset.
2) Additional policies referenced or cited within each policy are collected as supplementary data based on the foundational dataset.
3) The official websites of the Chinese central government and provincial-level governments were searched using the keyword "application-oriented" to collect and supplement other policies related to application-oriented talents cultivation.
4) Texts from internal working meetings of various institutions with minimal substantive contents are excluded to ensure the accuracy of the dataset's analysis results.

5) Some of the collected policies may have become obsolete. However, these expired texts are also included in the analysis dataset to reflect the dynamic nature of legal regulations and policy releases over the years and analyse policy content changes.

2 METHODOLOGY

2.1 Data and Methodology for the Evolution of the Central Government's Policies Contents Analysis

In order to identify the critical contents of China's application-oriented talents cultivation policies, we analyse the policy content changes in general and in different stages. On October 23, 2015, the Chinese Ministry of Education, National Development and Reform Commission, and Ministry of Finance jointly issued the policy *"Guiding Opinions on Guiding Some Provincial-level (non-key) Undergraduate Universities to Transform into Application-oriented Universities"*, which marked the establishment of specific policy guidelines for the transformation and development of provincial-level undergraduate universities and provided clear guidance for the cultivation of application-oriented talents in China. After the promulgation of this policy, the specific measures for cultivating application-oriented talents in China showed significant improvement. Therefore, this policy is symbolic of cultivating application-oriented talents in China. Consequently, this study categorises the application-oriented talents cultivation policies at the central level in China as follows:

Stage 1: Exploration of Application-oriented Talents Cultivation

Stage 2: Guiding Some Provincial-level (non-key) Undergraduate Universities to Transform into Application-oriented Universities

Stage 3: Construction and Development of Application-oriented Universities

2.1.1 Policy Text Segmentation

Chinese Word Segmentation in this study is performed using the Jieba segmentation tool (https://github.com/fxsjy/jieba). Four widely used Chinese stop-word libraries are loaded for stop-word processing.

2.1.2 Keyword Extraction and Evolution Analysis

In this study, keyword extraction was performed on the segmented results of policy texts using the TF-IDF algorithm. We collected statistics and analysed the changes in keywords in the central government policy in general and different stages.

For the overall analysis of the central government's policies (covering all policies), the following steps were taken: Firstly, the TF-IDF algorithm was used to filter out keywords from all texts, and nominal terms such as "should" "establish" were removed, resulting in the selection of the top 20 keywords. Next, the TF-IDF values of these top 20 keywords were computed for each time slice within the three stages, reflecting their importance in each stage. Finally, line graphs were used to illustrate the changes in these general keywords in the three stages.

The following steps were taken to analyse keywords by stage: Firstly, we segment the policies. Then, the TF-IDF algorithm was applied to each stage to extract keywords, and the top 20 keywords were selected. Finally, a comparison was made to analyse the variations of these keywords across different stages.

2.2 Data and Methodology for the Provincial-level Governments' Policies Analysis

As mentioned earlier, the importance and significance of the policy "*Guiding Opinions on Guiding Some Provincial-level (non-key) Undergraduate Universities to Transform into Application-oriented Universities*" is significant. Therefore, We took this policy as the core foundation to explore provincial-level governments' responses. We measure the response time (T_i) of provincial-level governments' response to the core central policy. The calculation formula is as follows:

$$T_i = Y_{Response} - Y_{Publication} \tag{1}$$

In this regard, T_i stands for the response time, measured in months; $Y_{Response}$ represents the year of the province i's first response to the core central policy, and $Y_{Publication}$ is the year of publication of the core central policy.

3 RESULTS AND DISCUSSION

3.1 Content Changes in Application-Oriented Talents Cultivation Policies Based on Keywords Analysis

In this section, we analyse the overall contents and its changes in application-oriented talents cultivation policies at the central level in China.

3.1.1 Contents in the Central Government's Application-oriented Talents Cultivation Policies

To understand the overall essential content units, we analysed the top 20 keywords in terms of importance in the policy texts. These essential keywords and their variations across the three stages are presented in Table 1 and Figure 1, respectively.

Table 1. Top20 Keywords in the Central Government's Policies

Number	Keywords	TF-IDF	Number	Keywords	TF-IDF
1	Technology	0.2473	11	Teacher	0.0561
2	Pilot	0.1451	12	Standard	0.0528
3	Major	0.1286	13	Teaching	0.0528
4	Enterprise	0.1187	14	Practice	0.0495
5	Innovation	0.1154	15	Characteristic	0.0462
6	Industry	0.0923	16	Training	0.0462
7	Admission	0.0791	17	Level	0.0396
8	Evaluation	0.0791	18	Strategy	0.0396
9	Area	0.0693	19	Course	0.0396
10	Classification	0.0660	20	Base	0.0396

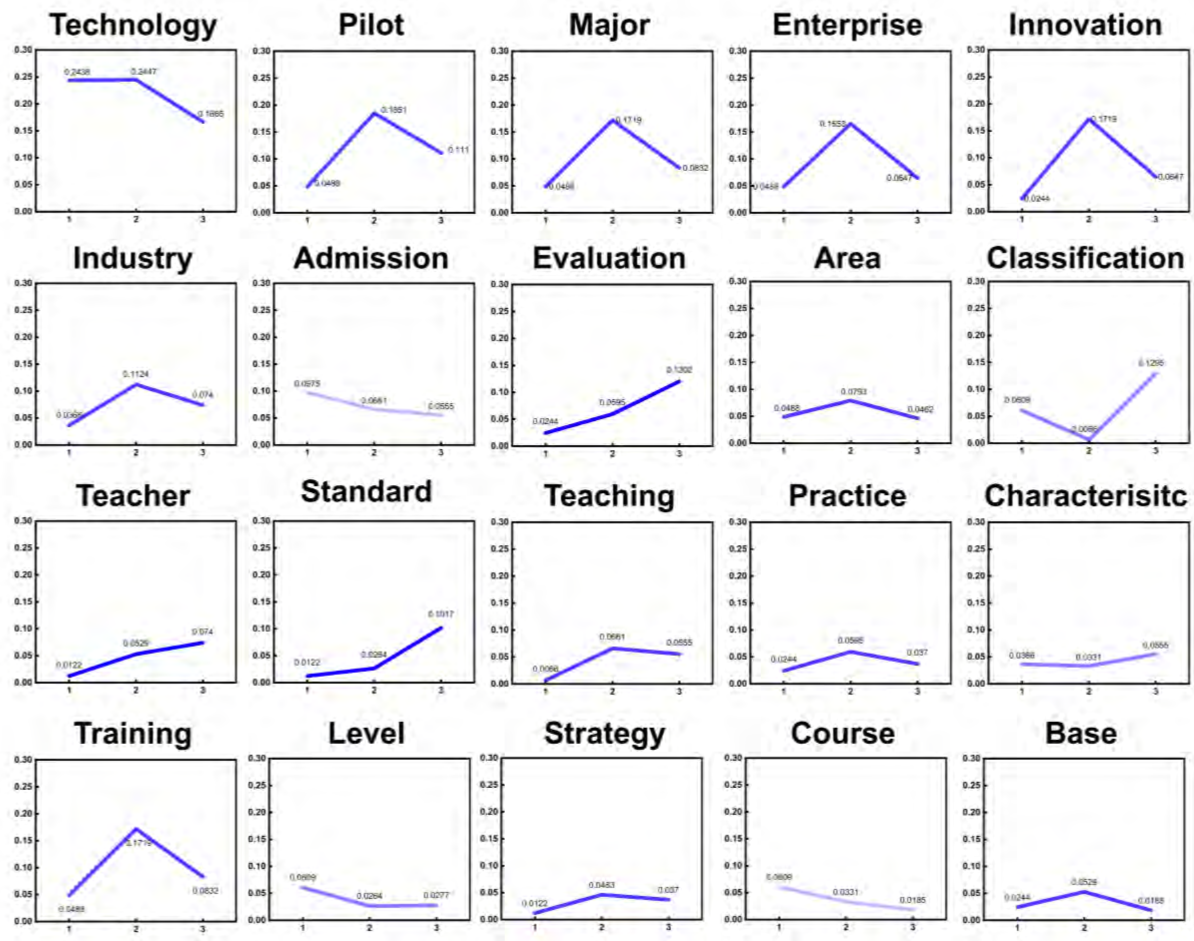

Fig. 1. Changes in TF-IDF values of Top 20 Keywords in Central Policies

In Figure 1, we present the changes in TF-IDF values of the Top 20 keywords and distinguish different categories using blue lines with varying transparency. The horizontal axis denotes distinct stages, whereas the vertical axis signifies TF-IDF values. Overall, the central policies for cultivating application-oriented talents revolve around "technology", "pilot", "major", "enterprise", and "innovation". The term "technology" is essential in all stages, indicating that China's policy for cultivating application-oriented talents focuses on specific technological innovation and integration with enterprises. With the significant increase in the importance of "evaluation" and "practice" and a relatively gradual decrease in the importance of "admission", "level", and "course", it can be inferred that China is gradually emphasising the optimisation of the evaluation system for application-oriented talents cultivation, shifting from the initial focus on course levels and professional licensing to the enhancement of practical operational abilities. In the third stage, the importance of the term "teacher" also continues to increase, indicating that China is increasingly emphasising the impact of teachers' capabilities on talent cultivation and gradually expanding the scale of teachers with rich practical experience from the business sector.

3.1.2 Changes in the Central Government's Application-Oriented Talents Cultivation Policies

To further understand the policy changes across different stages, we analyse the Top 20 keywords in three stages (as shown in Table 2). We use colour blocks to indicate the variation of these keywords. Each grey block in the table represents the keywords that will disappear in the subsequent stage, orange blocks represent newly introduced keywords in the current stage, and blue blocks represent keywords that are introduced in the current stage but will disappear in the subsequent stage.

Table 2. Top 20 Keywords in Different Stages

	Stage 1		Stage 2		Stage 3	
Number	**Keywords**	**TF-IDF**	**Keywords**	**TF-IDF**	**Keywords**	**TF-IDF**
1	Technology	0.2438	Technology	0.2447	Technology	0.1665
2	Scale	0.1097	Pilot	0.1851	Classification	0.1295
3	Admission	0.0975	Innovation	0.1719	Evaluation	0.1202
4	Graduate	0.0731	Major	0.1719	Pilot	0.1110
5	Classification	0.0609	Enterprise	0.1653	Training	0.1110
6	Level	0.0609	Industry	0.1124	Standard	0.1017
7	Course	0.0609	Area	0.0793	Major	0.0832
8	Area	0.0488	Entrepreneurship	0.0661	Teacher	0.0740
9	Major	0.0488	Admission	0.0661	Industry	0.0740
10	Pilot	0.0488	Teaching	0.0661	Advanced-level	0.0740
11	Enterprise	0.0488	Evaluation	0.0595	Enterprise	0.0647
12	Characteristic	0.0366	Experiment	0.0595	Innovation	0.0647
13	Guidance	0.0366	Practice	0.0595	Qualified	0.0555
14	Demand	0.0366	Internship	0.0595	Teaching	0.0555
15	Industry	0.0366	Employment	0.0529	Characteristic	0.0555
16	Mutual Recognition	0.0366	Government	0.0529	Admission	0.0555
17	philosophy	0.0244	Base	0.0529	industry-education integration	0.0462
18	Innovation	0.0244	Teacher	0.0529	Area	0.0462
19	Communication	0.0244	Strategy	0.0463	Certificate	0.0462
20	Practice	0.0244	Frontliner	0.0463	Conditions of Universities	0.0370

From the perspective of content changes in each stage, we can intuitively observe that the critical focus of policies has changed over time. The significant changes in each stage indicate the evolving hot issues in application-oriented talents cultivation. Moreover, during this stage, the guidance role of policies is still emphasised. The government highlights the recognition of credits between vocational and general education, which helps establish a bridge for two-way communication between vocational and general education.

In stage 1, the central government emphasise expanding the scale of application-oriented talents cultivation. It attaches importance to expanding the channels for universities to admit graduates from vocational schools. It encourages some universities to simultaneously admit outstanding in-service technical and skilled talents, graduates from vocational schools, and graduates from general and comprehensive high schools.

The policy "Guidelines on Guiding Some Provincial-level (non-key) Undergraduate Universities to Transform into Application-oriented Universities" provides more explicit and specific regulations regarding establishing application-oriented universities, which are the main entities for cultivating such talents. In terms of student engineering practical ability development, in addition to the previous emphasis on "practice", specific measures were further divided into "experiment", "practice", and "internship". Furthermore, this policy's significant significance is reflected in its precise requirements for teaching and teachers, making the cultivation more actionable. Additionally, the policy explicitly specifies various evaluation systems during the transformation process of provincial-level undergraduate universities into application-oriented universities, reflecting the guiding principle of "using evaluation to promote transformation".

In stage 3, it can be observed that the cultivation of application-oriented talents in China has become more standardised and specific in policy formulation. It can be confirmed by the appearance of the term "standard" in this stage and its relatively high TF-IDF value. Furthermore, adding the term "advanced-level" and "conditions of universities" indicate that this stage no longer focuses on expanding the scale but emphasises improving the quality. In stage 3, the central government has been exploring establishing a warning mechanism and exit mechanism, requiring higher education institutions that fail to meet the standards to rectify within a specified period.

Moreover, in terms of the university operating model, there is a growing emphasis on industry-education integration. The appearance of some specific terms also reflects critical events in this stage. For example, "certificate" reflects China's initiative to adapt to the demand for high-quality and multi-skilled technical personnel in response to the new technological revolution and industrial transformation. Since 2019, pilot programs for the "diploma plus certificates of vocational skills" have been launched in application-oriented undergraduate universities.

In addition, during stage 1, the central government emphasise establishing a classification system for different types of higher education institutions in China and differentiated levels for universities and talents. However, during stage 3, the emphasis shifts from hierarchical distinctions to more focus on types, reflecting the gradual equalisation of the status of application-oriented and research-oriented talents at the central policy level in China, with increasing attention given to engineering talents. Application-oriented talents and research-oriented talents are merely different types without hierarchical distinctions.

On the whole, the evolution of China's policy for cultivating application-oriented engineering talents follows gradual changes and is characterised by path dependence. At various stages, the central government has consistently placed great importance on the technical proficiency requirements of application-oriented talents. It has paid considerable attention to admission and majors' development. Application-oriented talents primarily utilise engineering theories and technical methods to achieve engineering objectives. Meeting the practical needs of local economic and social development has always been an important goal for application-oriented talents cultivation and Chinese engineering education. In terms of stakeholders, besides universities themselves, the role of enterprises has also been emphasised in the policies. In addition, pilot programs have been important initiatives for China to explore and implement application-oriented talent cultivation, serving as demonstrations through summarising good experiences. The term "innovation" has been consistently emphasised because innovation capability is a requirement for engineering talents and a significant response to China's strategy of promoting innovation-driven development through measures related to application-oriented talent cultivation and university construction.

3.2 the Provincial-level Governments’ Responses to the Central Government’s Policies

Given that China has a vertically decentralised political system, provincial-level governments have substantial autonomy in economic and social development. Therefore, provincial-level governments and their actions are essential for transforming and developing application-oriented talents cultivation. After the central government issues policies, provincial-level governments need to cooperate and implement them to achieve the desired cultivation and transformation, establishing a talent cultivation mechanism that meets the requirements of economic restructuring and industrial upgrading. We plot a figure of response time and the number of response policymakers (as shown in Figure 2).

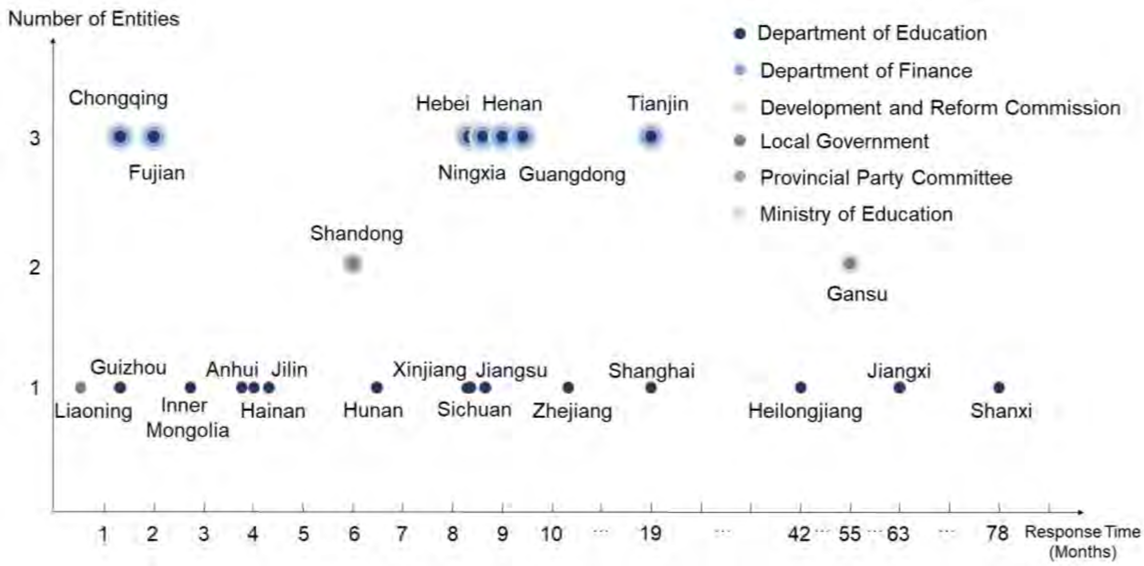

Fig. 2. Responses of Provincial-level Governments to Central Government’s Policies

Overall, 24 provinces, autonomous regions and municipalities responded to the core central policies, accounting for 80% (excluding Hong Kong, Macao, and Taiwan). The median response time is 8.16 months, and the average is 15.84 months. It means that the distribution of response time data is right-skewed, with response times concentrated in a small range of values but with some provinces having extreme values, resulting in longer overall response times. Specifically, the response time of each province varies significantly. Liaoning province has the shortest response time, 0.52 months, while Jiangxi province has the longest at 78.83 months. Beijing, Hubei, Yunnan, Shaanxi, Qinghai, and Tibet Autonomous Region do not have corresponding response policies. Among the response policymakers, the provincial-level education department is the most frequent single policymaker, while the situation of the three departments of "education department-finance department-development and reform commission" jointly formulating response policies is also common, and the situation in which two departments formulate the response policy is the least common. Shandong province is the only province in which the response policy was jointly issued by the provincial party committee and the provincial-level government, and Gansu province's response policy was jointly issued by the Ministry of Education and provincial-level governments, making it the only province in which a central government department formulates a provincial-level response policy. Seven provincial-level governments formulate response policies through the three departments of "education department-finance department-development and reform commission". On the whole, the number of response policies formulated by a single policymaker is higher than those formulated jointly by multi-policymakers.

4 SUMMARY

This study collects policies about cultivating application-oriented talents issued by the Chinese central and provincial-level governments. We analyse the policies' contents, changes and response characteristics using policy text analysis methods.

We found that:

1) Measures for cultivating application-oriented talents were mentioned in China as early as 2010 but required further specificity. In recent years, the Chinese government has demonstrated a more determined stance towards cultivating application-oriented talents, resulting in increasingly specific policy tools and measures. China has progressively shifted its emphasis from expanding scale to enhancing quality in cultivating application-oriented talents.
2) The evolution of China's policy for cultivating application-oriented talents follows gradual changes and is characterized by path dependence.
3) Most Chinese provincial-level governments have actively responded to the central government's policies and taken measures to cultivate application-oriented talents and construct application-oriented universities. However, there is a specific time lag in their response. Formulating response policies involving multi-policymakers can ensure the progress and implementation of policies to a certain extent. However, when it comes to the measures of Chinese provincial-level governments in application-oriented talents cultivation, the number of response policies formulated by a single policymaker is still higher than those formulated jointly by multi-policymakers.

There are some limitations in the current research:

1) The source of policy data needs to be enriched, and more data on some provincial-level governments' policy responses may affect the conclusions.
2) Due to the limited amount of provincial-level response data, the current study needs to differentiate between policy dissemination, policy reference and implementation, and the implicit responses of provincial-level governments, which may lead to deviations from the actual situation.
3) Further research is needed to investigate the underlying reasons and impacts behind the results presented in this study. For example, whether the response

speed of provincial-level governments and the number of policymakers would impact the quantity and quality of application-oriented talents cultivation.

To overcome these limitations, we will concentrate on the following enhancements: broadening the range of data sources through web scraping and other methodologies to gather a more extensive collection of pertinent policy and distinguishing various types of provincial-level governments' policy responses to gain deeper insights. Additionally, we will conduct more field research to thoroughly investigate the factors that influence the phenomenon.

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A multimodal measurement of the impact of deepfakes on the ethical reasoning and affective reactions of students

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Abstract

Deepfakes - synthetic videos generated by machine learning models - are becoming increasingly sophisticated. While they have several positive use cases, their potential for harm is also high. Deepfake production involves input from multiple engineers, making it challenging to assign individual responsibility for their creation. The separation between engineers and consumers may also contribute to a lack of empathy on the part of the former towards the latter. At present, engineering ethics education appears inadequate to address these issues. Indeed, the ethics of artificial intelligence is often taught as a stand-alone course or a separate module at the end of a course. This approach does not afford time for students to critically engage with the technology and consider its possible harmful effects on users. Thus, this experimental study aims to investigate the effects of the use of deepfakes on engineering students' moral sensitivity and reasoning. First, students are instructed about how to evaluate the technical proficiency of deepfakes and about the ethical issues associated with them. Then, they watch three videos: an authentic video and two deepfake videos featuring the same person. While watching these videos, the data related to their attentional (eye tracking) and emotional (self-reports, facial emotion recognition) engagement is collected. Finally, they are interviewed using a protocol modelled on Kohlberg's 'Moral Judgement Interview'. The findings can have significant implications for how technology-specific ethics can be taught to engineers, while providing them space to engage and empathise with potential stakeholders as part of their decision-making process.

1 Background

In this paper, we introduce a mixed-methods measurement method that allows us to study the effects of educating engineering students about the ethical and technical aspects of a specific technology on their moral judgement. The technology here is deepfakes, a form of Generative Artificial Intelligence (AI), which are synthetic videos created using machine learning (ML) models. As part of this study, we create a space for students to articulate their emotional experience and for us to capture their attentional data when watching deepfake videos. We believe that this approach may explain how students apply their ethical education when engaging with stakeholders as an important step towards developing their moral judgement.

1.1 Rise of Deepfakes - the promise and the danger

The fields of ML and AI have made tremendous advances over the past decade, particularly in computer vision, computational linguistics, and human-computer interaction (Wang and Keng, 2019). These advances have been made possible due to a combination of novel, sophisticated ML algorithms, large multimedia datasets, and powerful graphics-related hardware to optimise training.

Generative AI refers to a class of AI predictive methods that can generate different types of data in the form of synthetic media - text, image, audio, video - using existing data of the same format (Westerlund, 2019). Deepfakes are a type of synthetic media, often audio/video, produced by a combination of generative AI. Deepfake is a portmanteau of "deep learning", a class of ML algorithms involving the use of artificial neural networks and "fake", as in unreal. Deepfake media are created by manipulating or replacing the original audio/video with fabricated or altered content, often making it difficult to discern the authenticity of the resulting media (Karnouskos, 2020). Broadly speaking, deepfakes can be categorized into three types:

1. Head puppetry/Face swapping – A video is created to show a synthesized person's head and shoulders that mimics the behaviour of a real person's head movements. Video of the real person is used as source material for deepfake creation. In some instances, the synthesis person can be used on another real person's face.
2. Lip-syncing – A video is created with new audio by manipulating the lip movement of the person's face in the source video such that in the final deepfake video, the person appears to say something different to what they said in the original video.
3. Voice Cloning – This technique is used to generate audio-only media, in which a simulated voice is created based on multiple audio samples of the real person's voice such that the simulated voice is similar in sound to the real person.

Deepfakes have been used for numerous creative and constructive purposes in a wide range of avenues including healthcare, commerce, fashion, and education (Westerlund, 2019). At the same time, they are more commonly associated with producing content that ranges from hilarious to nefarious. Indeed, there are significant ethical issues to be grappled with in addressing the threats they pose to the public (Whittaker, 2020). Specifically, deepfakes have been used to misrepresent individuals and misinform the public. Being a target of a deepfake can also lead to loss of trust and credibility, as false actions or statements attributed to individuals can spread rapidly through social media, creating confusion and misinformation. The potential harm to individuals' personal and professional lives as a result of being targeted by deepfakes is gravely concerning. Indeed, multiple commercial as well as free software are easily accessible that allow users to create life-like deepfakes regardless of their intended purpose. The number of successful companies developing this kind of technology is increasing. They are recruiting skilled engineers, who could contribute to the incorporation of ethical thought in their practice. Therefore, there is an urgent need to train engineers about the ethical issues with deepfake technology, which we detail in the next section.

1.2 Lack of Responsibility

The production and use of deepfakes can involve a number of steps, with inputs from a wide variety of actors. This includes the engineers who develop the algorithm, create the datasets, train the model, test it for specific applications, before releasing it to the public who can then customise the technology to create deepfakes for the applications of their choice. Therefore, when individuals are targets of misrepresentation due to non-consensual creations of deepfakes, the responsibility of this harm becomes difficult to attribute to one person alone - this is a classic example of the “many hands” problem in engineering ethics in which the attribution of individual responsibility becomes extremely difficult in collective settings (Van de Poel and Roayakkers, 2011).

In addition to the difficulty of determining accountability, there is an added effect of the distance between the engineers who develop the algorithm and the one who is “deepfaked”. This separation between the producers of the deepfake technology and those affected by their production increases the risk of producers feeling released from the traditional social obligations towards the latter. There is a perception commonly held among some engineers involved in technology development that the responsibility for the consequences of the technology's use falls on others rather than themselves (Isaac et al., 2023).

Moreover, prevailing ideas of software technologies being objective (or a net positive) and unaffected by the values of the developer allow producers of deepfakes to free themselves of social obligations to those affected by deepfake dissemination (Griffin et al., 2023). This is compounded by the prevailing notion that ethics is a management issue and not an engineering one.

While computer engineers may consciously or subconsciously not consider their ethical responsibility, the technologies that they create have major ramifications in terms of the negative effects on the individuals who are being deepfaked. It can result in reputational damage, emotional distress, and violation of privacy, particularly in cases of revenge porn where someone's face can be swapped onto explicit content without their consent.

1.3 Ethics Education in Computer Engineering

In recent years, there has been a spate of novel approaches to integrate ethics in software and computer engineering curricula that would seek to introduce ethics at multiple levels of the study program (Horton et al., 2022; Grosz et al., 2019). However, in most computer engineering programs, ethics is taught as a stand-alone course as part of the department’s sole ethics course (Fiesler et al., 2020) In some other programs within computer science, ethics is taught in different courses but as a separate module (Grosz et al., 2019). Moreover, ethics education is often interchangeable with teaching the Code of Ethics as prescribed by different professional organizations in the discipline (Fiesler et al., 2020). While these are all important and necessary efforts towards creating more ethically-minded engineers, they are not sufficient because they do not provide enough time for students to critically engage with the ethical aspects of each technology concept that is taught to them. In order to facilitate this critical engagement, the ethical issues of specific technologies need to be taught along with the technology itself (Martin et al., 1996). This form of intervention would allow educators to emphasize the social responsibility of engineers as technology creators throughout the curriculum.

Indeed, there is a growing need for this form of intervention to address the ethical concerns associated with deepfakes in engineering education. As deepfake technology becomes more advanced and accessible, engineering students and professionals are increasingly able to create realistic fake media (Kietzmann et al., 2020). This raises ethical concerns related to the potential misuse of deepfakes, such as spreading misinformation, manipulating data, and violating privacy and consent. Engineering education programs must incorporate discussions on the ethical implications of deepfakes, including the responsible use of the technology and the potential consequences of its misuse.

Therefore, it is important to intervene as early as possible in engineering education to instil this sense of responsibility amongst engineering students towards potential stakeholders of their technological creation, such as deepfake technology, so that they can develop the ability to make ethical decisions. An important consideration in fostering ethical decision-making skills is that it is an entirely cognitive exercise i.e., our ethical decisions are defined by a combination of factors, including emotional relationships with oneself and others (Riley, 2013).

2 Experimental Design

In this study, we aim to compare the effects of a computing education topic, here deepfakes, that includes both technical and ethical aspects with one with a purely technical education on engineering students. Specifically, we are interested in two assessing two effects. One, the impact of the educational content on - 1) students' attention and emotionality with respect to their engagement with authentic and deepfake representations of a person and, 2) students' moral judgement in ethically ambiguous situations. Our proposed method consists of a human subject study with three phases - an *Education phase*, an *Engagement phase,* and an *Interview phase*.

2.1 Education Phase

The purpose of the *Education Phase* is to provide a short education to subjects regarding specific aspects of deepfake technology. The technical aspects put emphasis on learning what deepfakes are, how to recognize them, identify common audiovisual artefacts, and distinguish between genuine and manipulated media. Deepfakes present a multitude of ethical dimensions, but our intent is to highlight one in particular - the relationship between the technology creator (the subject) and the target/unintended stakeholder (the person who is deepfaked). Thus, the ethical aspects of the educational content are centred on the profound impact of deepfakes on targeted individuals through their non-consensual misrepresentation. The ethical education is created with the intention of fostering empathy and instilling a sense of responsibility in the subject towards the victims of deepfake manipulation. At the end of the *Education Phase*, the subject should have a clear idea of their role as technology creators, which should enable them to make informed and responsible decisions.

2.2 Engagement Phase

The *Engagement Phase* is designed to give subjects an opportunity to connect with an individual, targeted by deepfake creation. The subjects watch an authentic/unaltered video of an HR person giving a recruitment talk for their engineering company. The unaltered video allows subjects to witness the HR person's genuine form and expressions in an unmanipulated context so that subjects develop a baseline understanding of their appearance and demeanour. Then, the subjects watch two deepfake versions of the authentic video in which both the audio and video have been altered, whereby the altered recruitment talks differ from the unaltered one in terms of the person's speech, tonality, and sincerity. The purpose of making the subjects watch two different types of deepfake videos is threefold.

One, subjects are asked to assess the quality and content of the deepfake videos they observe. The subjects' evaluations help us understand how they evaluate the authenticity of the manipulated media. The subjects' attention to common deepfake-related production flaws is also an important indicator because these artefacts may raise suspicion towards the person in the video and/or be distracting from what the person says.

Two, the videos let the subjects reflect on their social emotional response toward the person in the video based on a three-axis model developed to ascertain student-relationships in classrooms i.e. assertion, affiliation, and attachment (Tormey, 2021). Therefore, this measurement enables the subjects to express their relationship towards the person in each of the videos. Since the video is a recruitment talk, this indicator may describe the subjects' perceptions of the HR person's professionalism.

Three, the videos also allow the subjects to introspect their culpability as potential creators of the video i.e., when confronted with the possibility that they had a role in creating these deepfake videos, the subjects' have an opportunity to express their moral emotions that they experience (Haidt, 2013). These moral emotions are a combination of emotions that are self-conscious emotions and those projected on the deepfaked person.

In summary, the *Engagement Phase* allows subjects to apply their knowledge from the *Education Phase* to distinguish between genuine and manipulated media, express their emotionality and attention towards the person in each video, and confront the potential ethical implications and consequences of their actions as deepfake producers.

2.3 Interview Phase

As part of the *Interview Phase*, our primary objective is to assess the subjects' level of moral judgement by employing Lawrence Kohlberg's framework of Moral Development that comprises three stages: Pre-conventional, Conventional, and Post-conventional (Kohlberg, 1971). To investigate the impact of ethics education on their moral development, we are interested in understanding the effects of undergoing the *Education* and *Engagement Phases*. We can gauge the potential influence of the educational interventions on their ethical decision-making abilities and the evolution of their moral outlook by evaluating their moral reasoning and judgement throughout the study.

We use the Neo-Kohlbergian Defining Issues Test, specifically adapted to Engineering Sciences, known as the Engineering and Science Issues Test (ESIT) for this examination (Borenstein et. al., 2010; Kotluk and Tormey, 2022). This test involves presenting the subjects with a set of three distinct cases, each highlighting an ethical dilemma. These cases revolve around the creation, utilization, and dissemination of deepfake technology as well as its potential impact on individuals. During the test, the subjects are required to read and analyse each case individually. Subsequently, they are prompted to make moral judgements and offer justifications for their decisions. Specifically, we try to ascertain their sensitivity to the issue presented in the case, their motivation to address it urgently, and their reasoning in identifying decision criteria.

By employing the ESIT, we can observe the subjects' ethical considerations that guide their decision-making and thus evaluate the subjects' moral development. This tailored assessment tool enables us to assess their moral judgements, reasoning abilities, and the ethical frameworks they employ when confronted with complex dilemmas involving the creation and use of deepfake technology. Through this comprehensive analysis in the *Interview Phase*, we aim to shed light on the potential impact of ethics education on the moral sensitivity and reasoning of engineering students

3 Methodology - Implementation and Data Collection

In this section, we describe how the three different phases are implemented and what methods are used to collect data during each phase. As mentioned earlier, we conduct a human subject study to investigate the effect of teaching ethical aspects of a computing education topic alongside technical aspects on the moral development of subjects. The computing education topic is deepfakes - its production, detection, and impact on targeted individuals. We pay specific attention to the role of engaging with deepfaked individuals on subject attention and emotionality.

To ensure a controlled environment, we recruit engineering students (bachelor's and master's), who possess a limited understanding of deepfakes. The decision to select subjects based on this criterion is motivated by our desire to assess the impact of our interventions on individuals who may not be fully familiar with the intricacies of this emerging technology, but are most likely to be potential creators of similar AI technologies. The subjects participating in the study are divided into two groups: the control group and the test group. As shown in **Figure 1,** the subject study is conducted in the three phases in chronological order, one subject at a time. During the *Education Phase*, the control group receives only the technical education, whereas the test group receives both the technical and ethical education about deepfakes. During the *Engagement* and *Interview Phases*, both groups receive identical treatment, ensuring that the observed differences can be attributed to the intervention in the *Education Phase*.

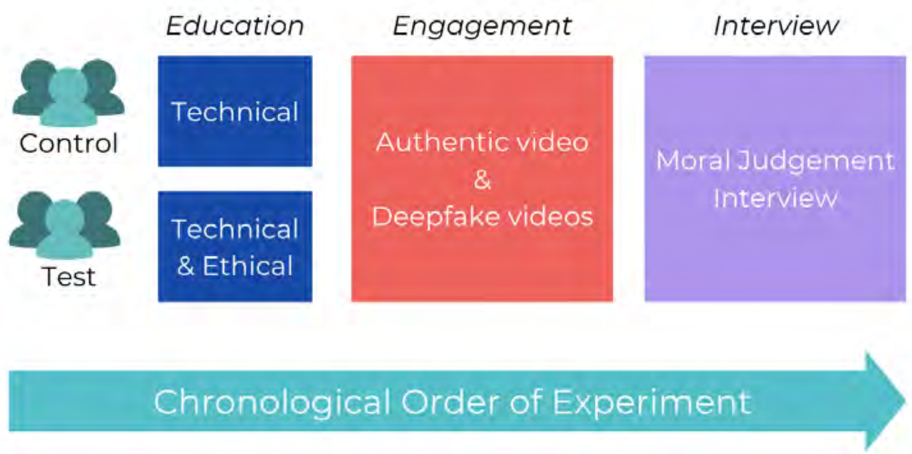

Figure 1: The chronological order of the subject study for each subject consists of three phases - Education, Engagement, and Interview

During the experiment, the subject is seated at a table facing a monitor with access to a mouse and a keyboard. In addition, an eye tracker (Tobii Pro Fusion) is mounted on the monitor and calibrated for each subject at the beginning of the experiment. Also, a video camera is mounted on a separate stand behind the monitor and positioned such that it records each subject's face. A separate monitor, keyboard, and mouse is placed adjacent to the subject's monitor, which is controlled by the experimenter. **Figure 2** shows the experimental setup that is used for running the subject study. The human subject study is approved by the EPFL Human Research Ethics Commission (HREC), provided that subjects' give their informed consent to participating in the study.

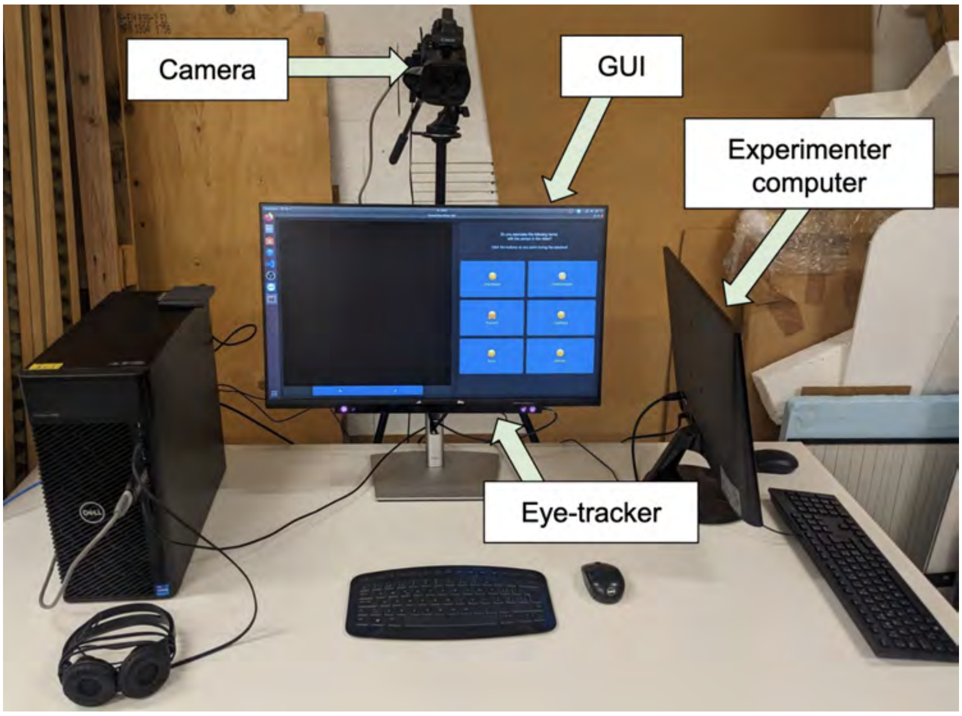

Figure 2: The experimental setup used to perform the human subject study, consisting of a computer for the subjects to interact with a graphical user interface (GUI), a computer for the experimenter, an eye-tracker to monitor their eye gaze movement, and a camera to record their facial expressions.

3.2 Education Phase

In the *Education Phase*, the control group exclusively receives technical education focused on what deepfakes are and how they can be detected. Subjects watch a video, entitled Education Video 1, nested in a graphical user interface (GUI) featuring the experimenter. During the video, the experimenter describes what defines deepfakes are and how they are created. Furthermore, the experimenter provides key steps to distinguish manipulated media like deepfakes from genuine media by paying attention to audiovisual artefacts. The script used for Education Video 1 is as follows:

"*Deepfakes are synthetic media created using deep learning algorithms to replace or superimpose a person's image, voice, or behaviour with that of another. Here are the steps to detect a deepfake. Firstly, look for any visible distortions or glitches in the video, such as mismatched lighting or blurry edges around the face. This can be a tell-tale sign that the video has been digitally manipulated. Secondly, pay attention to the audio quality. Deepfake algorithms often struggle to replicate natural speech patterns, resulting in distorted or robotic-sounding speech. Thirdly, analyse the movements of the subject in the video. Are the movements smooth and natural or do they appear jerky or robotic? If the movements seem stiff or unnatural, it could be a sign that the video is a deepfake.*"

The test group subjects receive a technical and an ethical education about deepfakes, in that order. The subjects in this group also watch Education Video 1, followed by a second video, entitled Education Video 2, in which the experimenter describes the real-world effects of deepfake technology on the lives of individuals who are misrepresented, often without their consent. The purpose of Education Video 2 is to instil a sense of responsibility and ethical awareness in combating the detrimental effects of deepfakes. The script for Education Video 2 is as follows:

"*Deepfakes are not just a technological issue, they also raise significant ethical concerns, particularly in terms of how they can affect the person who is deepfaked. While deepfakes can be used for harmless entertainment purposes, they can also be used to harm individuals in various ways. A deepfake video can be used to defame or embarrass a person, by depicting them engaging in illegal or unethical behaviour. This can have serious consequences for the person's reputation and may impact their personal and professional life. Even if the deepfake is proven to be fake, the damage may already have been done. Furthermore, the process of creating deepfakes often involves using images or videos of real people without their consent, which raises privacy concerns. This can be particularly distressing for individuals who have been victims of revenge porn or other forms of online harassment.*"

3.3 Engagement Phase

The *Engagement Phase* is meant ton assess the effectiveness of imparting the information in the *Education Phase* on subjects' ability to detect deepfakes and recognize ethical issues through gaze-based attention and emotional expression. This phase involves subjects watching three videos - Engagement Video 1, Engagement Video 2, and Engagement Video 3. These videos feature the same individual, an HR person from an engineering company called Protos. The subject watch each of these videos in chronological order. Engagement Video 1 is authentic, and it features an HR person promotes the company's open positions. Measurements pertaining to this video provides a baseline for subjects' attention and emotional response. The script for Engagement Video 1 is as follows:

"I am an HR Manager at Protos. We are an engineering company that is looking for talented individuals to join our team, and today I am here to tell you about the exciting opportunities we have available. At Protos, we value innovation, creativity, and hard work. We believe that by hiring the best people, we can achieve great things together. That's why we are looking for individuals who are passionate about engineering and who want to make a difference in the world. We offer a range of positions across various departments, from software development to mechanical engineering. Whether you are a recent graduate or an experienced professional, we have something for you. At Protos, we are committed to creating a diverse and inclusive workplace where everyone can thrive. We believe that diversity brings fresh perspectives and new ideas, and we are committed to ensuring that everyone feels welcome and valued. So, if you are looking for an exciting career in engineering, I encourage you to apply for one of our open positions. Thank you for considering Protos as your potential employer. We look forward to hearing from you soon."

In comparison, Engagement Videos 2 and 3 are deepfakes that misrepresent the HR person in different ways. Engagement Video 2 is meant to portray the HR person as disingenuous, whereas Engagement Video 3 is meant to depict them as incompetent. These different scenarios allow us to compare the measurements with the baseline for Engagement Video 1. In each of the deepfakes, visible production flaws are present in the form of artefacts around the person's mouth, facial expressions, and tonality to clearly indicate to the subject that they are watching deepfakes. The scripts for Engagement Video 2 and 3 are as follows:

“I am an HR Manager at Protos. We are an engineering company that is looking for talented individuals to join our team, and today I am here to tell you about the exciting opportunities we have available. At Protos, we say that we value innovation, creativity, and hard work. The company website says that by hiring the best people, we can achieve great things together. That message is important for the public. That's why we are looking for individuals who are going to help us create that impression for our customers. We offer a range of positions across various departments, from software development to mechanical engineering. Whether you are a recent graduate or an experienced professional, we have something for you. At Protos, we say that we are committed to creating a diverse and inclusive workplace where everyone can thrive. That is what all companies (are supposed to) say these days … that we believe that diversity brings fresh perspectives and new ideas. Once again, this will be an important message for our employees to show to the public. So, if you are looking for a career in engineering, and can see the importance of creating the right impression for customers, I encourage you to apply for one of our open positions. Thank you for considering Protos as your potential employer. We look forward to hearing from you soon.”

“I am an HR Manager at Protos, We are "um" … like an engineering company? that is looking for A "um" … like talented individuals to join our team? At Protos, we value, like…, innovation, creativity, and hard work,…that kind of thing. We believe that by hiring the best people, we can … kind of … achieve ,like … uhhh… great things together. That's why we are looking for individuals who are …umm… passionate about … uhhh … engineering and who want to make a difference in the world. Hmm …. we offer a range of positions across various departments, from, like, software development to mechanical engineering. Whether you are a recent graduate or, like, an experienced professional, we have something for you …hmmm. At Protos, we are committed to creating …ummm … like, a diverse and, uhh ... sort of, inclusive workplace where everyone can thrive. We believe that, like, diversity brings fresh perspectives, kind of, and new ideas. So, if you are looking for an exciting career in engineering, I encourage you to apply for one of our open positions? Thank you for considering Protos as your potential employer. We look forward to hearing from you soon.”

For each video, two types of measurements are made - concurrent (during the video) and terminal (end of the video). Concurrent measurements provide real-time tracking of subject attention and emotional reactions towards the person in the video. Terminal measurements provide aggregate responses from subjects about their self-conscious and outwardly projected emotions, as well as their technical evaluation of deepfake quality and content. While concurrent measurements capture initial, unadulterated perceptions, whereas terminal measurements include refined responses subject to reflection.

2.3.1 Concurrent Measurements

There are three concurrent measurements made during each of the Engagement Videos:

1. The subjects express their social emotions towards the HR person in the video by clicking labelled emoticons in response to the HR person's actions/statements in real-time. These emoticons are categorized into three axes: attachment (trust/distrust), affiliation (warmth/coldness), and assertion (impressive/unimpressive) (Tormey, 2021). By using these emoticons, we can gather immediate insights into the subjects' emotional reactions and perceptions of the HR person's credibility, likeability, and competence.
2. The subjects faces are recorded using the camera, which are then processed by an open-source, locally installed facial expression recognition software, called EmoInfer (Sinha and Dhandhania, 2022). EmoInfer analyses and classifies each frame of the recorded video into stereotypical facial expressions as defined by existing facial emotion models. This data may give us some insight into subjects’ level of engagement and possibly their subconscious emotional responses.
3. The subjects’ eye gaze movement is tracked using the eye-tracker to ascertain which specific aspects of the video they pay attention. This data allows us to identify Areas of Interest and eye gaze fixations, which can indicate their ability to detect deepfake artefacts, as well as to convey emotional empathy to the person in the video.

2.3.2 Terminal Measurements

There are four terminal measurements that are made after each of the Engagement Videos:

1. Similar to the concurrent measurement of social emotions, the subjects respond to a questionnaire that uses the same three-axes model. For each axis, subjects rate the person's

characteristics on a 7-point Likert scale, from “Not at all” to “Very much” - trustworthiness, well-intentioned, reassuring, reliable, inspires confidence (attachment); friendly, warm, compassionate, positive towards viewer, caring (affiliation); and impressive, admirable, influential, exciting, inspiring (assertion). This measurement helps us to capture their subjective evaluation of the HR person's social attributes and emotional impact.

2. To complement the quantitive facial expressions recognized by EmoInfer, subjects watch the video recording of their faces alongside a time-synched screen recording of the GUI with the Engagement Video they watched. While watching the recordings, the subjects free-label their own facial expressions as they might be able to better recognize them.
3. For Engagement Videos 2 and 3 , subjects complete a questionnaire that tests their technical proficiency in engaging with a deepfake. They evaluate the quality of the videos - both visual (video) and auditory (audio) aspects, using a 7-point Likert scale. They also indicate the extent to which they paid attention to the quality and content of the video. Finally, they state whether they are able to detect that the video is a deepfake. This self-assessment helps us understand their confidence level in their deepfake detection skills.
4. For Engagement Videos 2 and 3, subjects respond to a questionnaire that pre-supposes their involvement in the creation of the deepfake videos. Based on this supposition, the subjects express their moral emotions - guilt, shame, embarrassment, pride, compassion, contempt, and disgust - on 7-point Likert scales. Their responses provide insight into their ethical sensitivity when confronted with the potential scenario of creators of harmful technology.

This comprehensive assessment comprising concurrent and terminal measurements enhances our understanding of the subjects’ experiences and allows us to draw meaningful conclusions about the effectiveness of the educational interventions and the impact of deepfakes on individuals.

3.4 Interview Phase

In the *Interview Phase*, the subjects read three ESIT-type cases, one at a time, that present ethical dilemmas related to the production, usage, and dissemination of deepfakes targeting individuals. After reading the case, the subjects must answer two questions to measure moral sensitivity and motivation:

1. Moral Sensitivity - “Is there an ethical issue in the case you just read? If you respond yes, then what is the ethical issue?”
2. Moral Motivation - “If you have identified an ethical issue, is there an urgency in addressing this issue? If you respond yes, then please elaborate.”

To measure their moral reasoning, subjects are presented with a set of 12 questions that relate to different levels of moral judgement. Using a Think Aloud Protocol (Bernadini, 2001), they are asked to evaluate the relevance of each question to the ethical dilemmas presented in the cases. Subjects select one of five options (“great”, “much”, “some”, “little”, “no”) to indicate the relevance of each question. This allows the subjects to critically engage with each criterion. Finally, subjects select four of the most important questions, in order, that are relevant to the case they read.

Their selections are used to calculate a numeric measure of post-conventional moral reasoning for each subject based on the ESIT scoring key. This scoring key assigns values to different levels of moral reasoning, allowing for a quantitative assessment of subjects' ethical decision-making processes. This quantitative measure is complemented by a qualitative analysis of the subjects' verbal responses that are recorded. Collectively, we can gain valuable insights into their moral sensitivity, moral motivation, and moral reasoning in evaluating ethically ambiguous situations involving the targeted deepfaking of individuals.

4 Conclusion

This paper describes a methodology that aims to investigate the effect of ethical and technical education of deepfakes on subjects’ deepfake detection skills, their attention and emotionality towards deepfaked individuals, and their moral judgement in ethically ambiguous cases. Presently, we are in the process of collecting data for the proposed study. While we have not made explicit hypothesis in this paper, we posit that the ethical education will promote test group subjects’ moral sensitivity, motivation, and post-conventional reasoning. Furthermore, it may highlight test group subjects’ ethical tendencies and encourage them to have more empathy towards deepfaked individuals than control group subjects through their gaze and emotional expression.

However, it is important to recognize that the results from this study may be difficult to generalize for a few reasons. One, the length of the experiment is approximately 60 minutes per subject and the *Educational Phase* lasts 15 minutes. Any transferable effects observed in this short timeframe to a classroom setting will need to be verified in a separate longitudinal study. Two, the social identity of the experimenter and that of the HR person may have unforeseeable effects on the results, depending on the social identity of each individual subject. Three, facial expression recognition, machine-read or self-reported, is a heavily contested measure because it is incumbent upon accepting the premise that there are specific universal emotions. While this is not an exhaustive list of possible limitations of this study, we believe that incorporating diverse data collection methods should help offset some of the challenges they pose.

We anticipate that a comprehensive mixed-methods data analysis will contribute to our understanding of the issues posed by deepfakes and other types of generative AI. Through this study, our aim is to develop novel and responsible uses of AI tools in education, especially to teach ethics to engineering students. Ultimately, the insights gained from this study should inform future educational initiatives and empower individuals to navigate the complex landscape of digital media with greater resilience and discernment.

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EXPLORING THE DEVELOPMENT OF ENGINEERING DESIGN CREATIVITY AND THE ROLE OF SPATIAL SKILLS IN THIS PROCESS

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ABSTRACT

This study aims to investigate the development of creativity in engineering education and how spatial skills relate to creativity of design solutions.

Undergraduate students in the first (n=86) and fourth/fifth year (n=48) of their engineering programme were invited to participate. Students completed four spatial tests to precisely measure visualisation skills. In a separate session, students were invited back to solve two engineering design tasks: a ping pong problem where they designed a ping pong ball launcher game to meet specified criteria and a rain catcher problem where they were tasked with developing as many ideas for capturing rainwater as a water source for a remote location as they could. Students were asked not to consider feasibility, cost, etc. and to come up multiple radical solutions to the rainwater capture problem.

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The creativity of design solutions was assessed using Adaptive Comparative Judgement. Statistical analysis indicated significant relationships between spatial skills, students' year of study and gender. A statistically significant relationship was also found between students' creativity scores on both design challenges. No statistical differences were determined in the creativity of first and fourth/fifth year students' solutions. These findings will be discussed relative to existing research, future work, and potential implications for education practice.

1 INTRODUCTION

Preparing future engineers to solve design problems in innovative and creative ways has become an essential component of engineering education programmes [1, 2]. Creativity is at the core of design practice and strategies to develop creativity have been incorporated into various engineering programmes with the intention of preparing graduates to solve real-world engineering problems in unique ways [1]. As engineering programmes have been striving to develop creativity for the last number of years it is important to assess whether the educational structures in place are in fact contributing to the development of creativity for solving design problems. This is timely as skills reports have outlined that design for engineering is a current and future skills need [3].

When considering the development of creativity in engineering education it is also pertinent to reflect on the role of spatial skills, a key predictor of success in Science, Technology, Engineering and Mathematics (STEM) [4]. Previous research has indicated a relationship between spatial skills and creativity [4 - 6]. As spatial skills are malleable [7], the development of spatial skills could support the enhancement of engineering graduates' creative design capacity throughout their undergraduate programme. Therefore, it is important that additional research is carried out to understand the relationship between spatial skills and creativity in various contexts and how this may apply to engineering education practices.

The study outlined through this paper aims to investigate the development of creativity in engineering education through an expertise comparison of design problem solving solutions. In addition, the study will also investigate the relationship between spatial skills and creativity in the context of performance on real-world engineering design problems similar to those employed on engineering education programmes.

2 METHODOLOGY

2.1 Setting and participants

This study was carried out at a large public R1 university and based in the College of Engineering and Applied Sciences. The research participants were undergraduate engineering students in the first and fourth/fifth year of their engineering programmes. Participants were recruited through flyers which were displayed across the college. The participants engaged in two research phases. Phase one consisted of participants completing four spatial tests to obtain a precise measure of spatial skills. In the second phase participants were required to solve two engineering design tasks. Ethical approval for this research was granted by the university's IRB committee.

2.2 Data collection

The participants recruited for this research consisted of undergraduate engineering students in the first (n=86) and fourth/fifth year (n=48) of their engineering programme. Students were compensated for their participation time with gift vouchers. During the first phase of data collection the participants completed four spatial tests: Mental Rotation Test (MRT), Mental Cutting Test (MCT), Surface Development Test (SDT), and Paper Folding Test (PFT). A verbal analogy test was also carried out at this phase of the research as a control for general intelligence.

In the second phase of data collection, the participants were invited to return to individually solve two engineering design tasks: a ping pong problem and rainwater catcher problem. Fig. 1 and Fig. 2 outline the problem statements that were provided to the participants.

In an attempt to avoid boredom at your residence hall, creative engineering students developed a challenging new game. A ping-pong ball is to be launched at a bullseye target, and points are awarded according to the accuracy of the landing. However, the ping-pong ball cannot be thrown at the target. It is up to you to design a device which will lift the ping-pong ball into the air and land it at the target. An accurate landing is desired while also maintaining a long flight time. Given that the center of the landing area is 5 meters away from the launch site, and the entire launching assembly must not be greater than 1m x 1m x 1m in dimension, design a ping-pong ball launcher for this game.

Your work should contain a detailed description of your design and should include any relevant diagrams and calculations. Please clearly state all assumptions which are needed in your analysis and try to keep your design simple yet effective.

Fig. 1. Ping Pong problem instructions to participants.

In remote villages throughout many rural, underdeveloped areas of the world, easy access to fresh clean drinking water is very limited. Villagers must often walk long distances to a fresh water source, collect the water in large, awkward bins, and then carry the water back uphill to their home. Retrieving the fresh drinking water in this manner takes tremendous amounts of time and effort. In many cases, however, rainwater is a fresh and abundant source of water, but there are no solutions for effectively capturing, storing, and distributing the water.

Design ways for remote villagers to catch and use rainwater. Your solutions should focus on creating totally new designs or developing totally new ways of approaching the problem. Don't be concerned about a particular cost or size of your solution, and feel free to choose any materials you desire, as those sorts of constraints might be able to be worked out in the future.

Develop multiple solutions for this problem. Focus on developing radical solutions. Try to develop solutions without concern for cost or immediate workability. Be sure to write each solution on a different piece of paper and use drawings as necessary to sketch your ideas. It's important that you do your best and continue working for the full time of the activity.

Fig. 2. Rainwater catcher problem instructions to participants.

Following this phase, the solutions created by each participant were collated and all ping pong problem solutions and rainwater catcher solutions were entered into two separate Adaptive Comparative Judgement (ACJ) sessions. ACJ is a holistic assessment tool which involves the pairwise comparison of items of work which leads to a rank order of performance based on a specified criterion, in this instance-creativity [8]. The assessors for these ACJ sessions were 108 undergraduate engineering students (n=60 assessors for the ping pong problem solutions and n=48 assessors for the raincatcher solutions). The reliability of an ACJ session is described by the Scale Separation Reliability (SSR) coefficient. In comparative judgement, there is a strong indication that this reflects an interrater reliability index [9].

3 RESULTS

Data collected for the purposes of this research was compiled in Microsoft Excel and was cleaned and analysed using IBM SPSS version 28.0.0.0.

3.1 Creativity development

The first element of the research aim was to investigate the development of creativity in engineering education. The reliability of the ACJ panel conducted to holistically assess creativity and determine a rank order of creativity amongst the cohort of participants was moderate ($SSR_{\text{ping pong problem}}$ = 0.59 +/- 0.02, $SS_{\text{rain catcher problem}}$ = 0.52 +/- 0.02).

An Independent samples t-test was conducted to address this research aim, examining the development of creativity during an undergraduate engineering programme. The development of creativity was assessed through an expertise comparison where first-year engineering students creativity ranks were compared to those of fourth/fifth-year engineering students who had engaged in the same programmes of study. Through this analysis no statistically significant differences were found between the creativity scores of first-year students (M = 134.61, SD = 78.002) and fourth/fifth-year students (M = 143.10, SD = 74.512) on the ping pong problem $t(131) = -.613$, $p = .541$. Additionally, no statistically significant differences were found between creativity rank and year of study on the rainwater catcher problem $t(126) = -.088$, $p = .930$.

This suggests that, as measured using ACJ in this context, creativity was not significantly developed during the progression of engineering students through their program of study.

3.2 Spatial skills

The second element of the research aim was to investigate how spatial skills relate to creativity of engineering students design solutions. The four spatial scores for the students were converted to composite z-scores to facilitate within sample comparisons.

A Spearmans correlation analysis was conducted to address the research aim as the spatial data was converted to rank data and the creativity data from the ACJ panel was also in a rank format. The results of this correlation analysis are outlined in Table 1 below. No statistically significant relationship was found between spatial skills and the creativity demonstrated on either of the design problems. A statistically significant correlation was found between the creativity students demonstrated in solving the ping pong problem at rain catcher problem. Additionally, a statistically significant positive correlation was found between spatial skills, year of study and gender. The correlation found between spatial skills and year of study indicates that students in the latter stages of their engineering degree programme were found to have higher levels of spatial skills. With respect to gender this finding indicates that males in the sample were found to have higher spatial skills than their female counterparts.

Table 1. Spearman correlation investigating the role of spatial skills in creativity.

Variable	1	2	3	4	5
1. Spatial skills	1.000	-.110	-.032	.279**	.234**
2. Ping pong rank		1.000	.305**	.052	-.112
3. Rain catcher rank			1.000	-.012	.104
4. Year of study				1.000	-.172
5. Gender					1.000

**. Correlation is significant at the 0.01 level (2-tailed).

4 SUMMARY

The aims of this research were to investigate the development of creativity in engineering education and the potential influence of spatial skills on the creativity of engineering students design solutions. The results outlined in section 3.1 indicate no significant differences in the creativity displayed by the first and fourth/fifth year engineering students. This is concerning as a core aim of engineering programmes is to foster the development of students creativity for design. Although, this finding does align with reports of a skills need in the area of design for engineering where there is a noted skills gap and demand in industry [3]. The findings are also similar to those of previous research which has indicated no differences in engineering students performance in another key skill, problem solving, through a similar expertise comparison [10]. The findings of the presented study suggest that more work is required in engineering education on the strategic development of creativity through engineering programmes.

Through this research no significant relationship was found between spatial skills and creativity. It had been anticipated that there would be a statistically significant relationship between these two factors as previous research has indicated a relationship between them [4 - 6]. A critical factor to consider here is the reliability levels achieved through the ACJ panel which was used as a measure of creativity in this research. The reliability of ACJ panels that are fully completed (i.e., all assessors have completed all judgements) in Technology education research is typically high, ~0.9 [8]. The reliability for the ACJ panel in this research was moderate, possibly due to the ACJ panels unfortunately not reaching full completion (i.e., some assessors did not complete all of their judgements). This may have impacted the statistical analysis for this work and as such, the findings should be tentatively considered until such a time that further work is presented to corroborate them.

5 ACKNOWLEDGMENTS

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EMPLOYMENT PATHWAYS FOR EMERGING TALENT: EVALUATING THE CERTIFICATE IN COMPUTER AND DATA SCIENCE (CDS)

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ABSTRACT

This research paper presents the results of the first evaluation of the learning experience, challenges and opportunities of the Certificate in Computer and Data Science (CDS). Specifically, it evaluates two different real-life experiential learning opportunities (ELOs): supervised internships and self-guided projects.

MIT Emerging Talent, an initiative that expands upon the efforts of the MIT ReACT (Refugee Action Hub), provides talented learners a platform to advance their skills, leverage their expertise, access a professional career, and become leading change agents in their communities. The CDS is a 12 month-long online learning program that opens education to employment pathways for emerging talent, including refugees, displaced populations, and underserved communities worldwide. The program combines rigorous academic curriculum, immersive skills workshops, networking events, mentor support, and experiential learning opportunities to provide learners with the knowledge, hands-on skills and experiences needed to accelerate their learning and professional journeys.

Quality education, work readiness, networking, and local support are critical for emerging talent to overcome the challenges they currently face and grow personally and professionally. Programs offering such opportunities and their impact are still poorly studied. In this paper we present the complete CDS learning journey and results from surveys and interviews to learners and program staff regarding the supervised internships and the self-guided projects. The paper concludes with recommendations and future steps.

1 INTRODUCTION

1.1 Opportunities for Emerging Talent

The world is at a pivotal moment. Current environmental, socioeconomic, and technological challenges are requiring humanity to be more sustainable and adaptable [1]. At the centre stage, to make it possible, is high-quality and opportune education [2,3]. However, neither the conditions nor the resources necessary to promote learning are evenly distributed in the world. In 2021, only 50% of children at scholar age attended upper secondary school or higher education [4]. This percentage drops to 40% for tertiary education enrolment [5], and is lower in low income, underrepresented communities [6]. Evidence suggests causality between education and socioeconomic empowerment, and sustainable development [7].

All around the world, people from historically excluded or underrepresented backgrounds, including refugees, displaced, underserved and conflict-impacted communities, have several of their basic needs unmet, including education [1,6]. Nevertheless, their resilience and unwavering spirit allow them to overcome such struggles and forge a promising future, if properly nurtured, to become agents of positive change. We refer to these stars as *emerging talent*. To nurture this talent, programs offering high-quality training, socioemotional support and connections with the job market are necessary.

1.2 MIT Emerging Talent

MIT Emerging Talent is an initiative at the Massachusetts Institute of Technology (MIT) that develops global education programs targeting talented individuals from the most challenging circumstances. This initiative expands upon the efforts of the MIT Refugee Action Hub (ReACT), which has offered the Certificate in Computer and Data Science (CDS) to more than 200 learners in the last 5 years [8].

Globally, there are several programs offering training and support to emerging talent. Programs focused on high-tech technical skills, usually cover coding and data science but lack mentoring and human skills training [9-10]. Conversely, programs with a strong community building and human skills component usually cover vocational training [11,12]. In general, these programs are evaluated via their mid- to long-term impact, but few include deep programmatic assessment nor combine technical and human skills training. In this research paper we present the first evaluation of the learning experience, challenges, and opportunities of the CDS.

1.3 The Certificate in Computer and Data Science (CDS)

The CDS is a one year long online learning program (offered in English) that bridges education and employment for emerging talent following the Agile Continuous Education (ACE) model; namely it combines individual learning, group learning, and a real-life mentored experience [8]. The program has four core offerings: Academics, Human Skills, Experiential Learning, and Networking. These offerings are achieved via synchronous and asynchronous academic activities, synchronous networking events, mentor support, and experiential learning opportunities (Figure 1). The program is open to refugees, internally displaced persons, and low income, historically marginalised learners over the age of 18 years old.

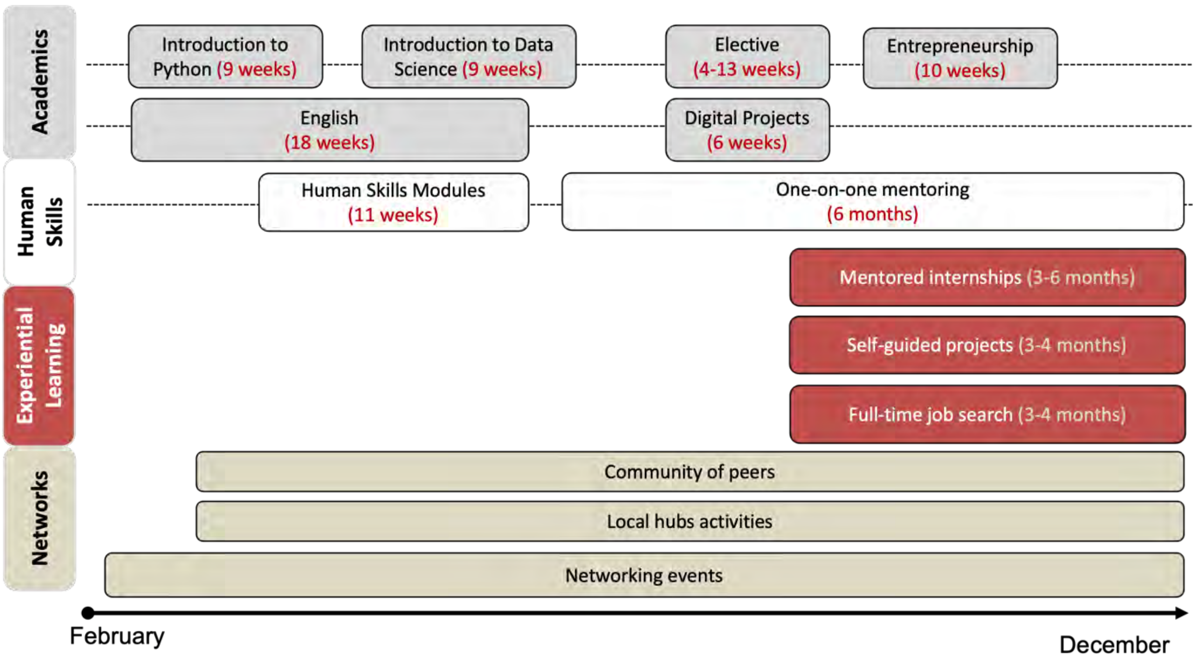

Fig. 1. The CDS Certificate core pillars – academics, human skills, experiential learning, and networks – and main program activities.

- **Academics**

Table 1 presents a detailed description of the core academic activities.

Table 1. Core academic activities for the CDS

Online, asynchronous, instructor-paced courses (2 courses)	*MITx Introduction to Computer Science and Programming Using Python* and *MITx Introduction to Computational Thinking and Data Science* courses (each requiring 15 hours/week, for 9 weeks).
Elective online course (1 course)	Learners were required to choose one elective from *MITx digital course library* to upskill in a field of their interest
English support	Learners were offered optional *English language lessons* and *one-on-one tutoring* through the NGO Paper Airplanes. Activities lasted 18 weeks, with a commitment of 5 hours per week.
Digital projects workshop (6 sessions)	Learners were invited to a *data science workshop* (six, two hours-long sessions) on web scraping, data cleaning and analysis; results presentation, and project management and collaboration.
Entrepreneurship	A subgroup of learners (10) participated in the *MIT Innovation Leadership Bootcamp*, an online, synchronous, 10-weeks long program focused on identifying an innovation opportunity, a solution, and selecting a business model.

- **Human Skills**

Training in human skills and mentoring was supported by Na’amal (Table 2).

Table 2. Human skills activities

Online synchronous human skills modules	Learners had access to 11 optional *online synchronous workshops* (1.5 hours each, offered 3 times to align with 3 different time zones) on planning, teamwork, communication, remote work, self-management, conflict resolution, and work in culturally diverse settings. The workshop videos were also available later, asynchronously.
One-on-one mentoring	Learners were paired with a mentor with similar cultural and personal background, to provide professional and personal mentoring.

- **Experiential Learning Opportunities**

The last 3-4 months of the program, once the technical training was completed, learners applied their skills and knowledge via an experiential learning opportunity (ELO). There were three different ELO modalities: paid mentored internships, self-guided projects, and full-time job search (more details in Table 3):

Table 3. Experiential Learning Opportunities (ELOs)

Paid mentored internship	Learners applied their skills at the workplace, built up their resume, and created connections with the local job market to, ultimately, get a full-time job. MIT Emerging Talent provided access to company databases, some internship opportunities, and connections with local partners, but learners were in charge of finding the internships (of minimum 20 work hours/week, for 3 months). Most host companies and interns were in different locations. Eighteen (18) learners from the cohort participated in the Global

	Apprenticeship Program (GAP), an initiative led by The Intern Group (TIG), that connects learners and companies with remote paid internships. For more details on the GAP initiative refer to Salazar-Gomez et al [13].
Self-guided projects	Learners with previous job experience, a full-time job, or without the time availability for an internship, proposed an individual or collaborative project. These projects allowed learners to improve their portfolio and confidence using the knowledge and tools learned in the program.
Full-time job search	Some learners needed to immediately find a full-time job, so MIT Emerging Talent offered this ELO to facilitate their employment search.

- **Networking**

Table 4 describes the networking activities, including local and remote events.

Table 4. Networking activities

Facilitated synchronous events	The program team organized synchronous online events throughout the program to promote engagement and community building, and to assess challenges and opportunities experienced by learners.
Community of Peers	Beyond the facilitated events, program participants were encouraged to build a network of support and friends to keep everyone engaged via Slack and LinkedIn channels.
Local Hubs	Where available, learners living nearby (same city) were connected with local partners (NGOs, employers, and higher education institutions) that provided spaces to meet in person, and plan community building activities.

2 RESEARCH METHODOLOGY

2.1 Program evaluation and assessment

All research activities were approved by MIT's IRB office. All participants (learners, industry mentors, supervisors, and program staff) were invited via email communications. Informed consent was provided to all research subjects.

- **Questionnaires and interview prompts**

Surveys and interviews were used to collect data regarding content, pedagogies, technology, and socioemotional support with emphasis on the supervised internships and self-guided projects. Pre- and post-questionnaires were deployed via Qualtrics; and interviews were done via Zoom. Surveys were deployed for learners, industry mentors, supervisors, and staff while only program staff were interviewed.

Pre-questionnaire: Learners were asked about their prior knowledge and mastery of technical and human skills (pre- and post-CDS), work/internship experience, what worked and did not work with the different CDS academic activities (pre-questionnaire was deployed right before the ELO), what their chosen ELO was and what were their ELO expectations prior to it. Internship mentors and supervisors were asked about their experience as a manager, their mastery leading teams and individuals from culturally diverse backgrounds, and the expected skills and content knowledge from interns. Program staff were inquired about the foreseen program challenges and opportunities, the elements of technical preparedness offered by the program, and factors supporting or affecting a successful ELO.

Post-questionnaire: Learners were asked about their mastery of technical and human skills, those that were key in their ELO, and the usefulness of the CDS activities and courses. They were also inquired about the ELO challenges and opportunities, their relationship with the supervisor, and satisfaction with the ELO. Mentors and supervisors were asked about their mastery level of coaching skills, the skills and knowledge considered important for the ELO, how support and feedback were provided, and how the ELO goals were set and met.

Interviews: Program staff were asked about the overall program perception, what worked and did not work, and how the relationship with mentors was. Staff were also asked about the ELO challenges and opportunities, the role of the local support mechanisms (if available), and the process of finding internships, defining projects, and supporting the job search.

3 RESULTS AND RESEARCH FINDINGS

A total of 94 learners, 21 supervisors (some oversaw several interns), and 7 program staff were invited to the surveys. A total of 11 (11.7%) and 10 (10.6%) learners, and 4 (19%) and 2 (9.5%) supervisors responded to the pre- and post- questionnaires, respectively. Two (2) program staff (28.6%) answered the pre-questionnaires and four were part of a deep exit interview. Given the low survey response rate, the following findings derive from the learners' enrolment and completion data as well as from the interviews and mixed method surveys.

3.1 Learner participation and program completion

The 2022 CDS cohort program took place in 2022. From a total of 1000 complete applications (3000 incomplete), 135 (13.5%) learners were accepted (by a committee of experts) and enrolled in the program. The admission criteria for the open call for applications included English fluency, interest in computer and data science, openness to collaboration across cultures, inclination towards social impact, problem-solving mindset, and math and statistics knowledge.

After two months of core academic activities, 94 (69.1%) from those enrolled continued participating. The program was completed by 65 (47.8%) learners. Completion required finishing the core academic courses and the ELO. Program attrition is an issue that reflects the pressing conditions some of this emerging talent is exposed to: no access to a computer, electricity service, or internet connection; time constraints due to other obligations including caring for family members and working several shifts; housing instability and more.

3.2 A global community of talent

The CDS is a global program: Figure 2 presents the locations for enrolled learners (135 in 31 countries), those that completed the program (65 in 28 countries), and the offices of the 20 companies (13 countries) hosting remote internships. Learners come from Africa, Asia, North, Central and South America, and Europe, with program local hubs in Afghanistan, Colombia, Greece, Jordan, Uganda, Uruguay, and USA.

*Fig. 2. Location of Learners **enrolled** and **graduated**, and **internship host companies.***

3.3 Program opportunities and challenges

Opportunities: Learners and staff highlighted upskilling in time management, communication and autonomy, teamwork, and digital literacy. The digital projects workshop was very useful for learners working on self-guided projects. The GAP experience proved successful to support CDS in finding paid internships. Active local hubs provided support and engaged with learners in their context and program staff highlighted the need of more local partners. The program provided means to promote community building and peer-to-peer learning.

Challenges: The learners' local socioemotional and economic conditions (limited access to technology, mental and physical health, displacement, lack of spaces for studying) make program participation challenging. Engagement between the MIT ReACT and Emerging Talent community and learners needs to be improved (for support and technical advice related to courses and projects). Producing content and activities engaging to learners in all ends of the professional spectrum is an unsolved issue (especially for learners seeking more challenging, in-depth, data science knowledge). Internships were the preferred ELO for most learners but finding them is one of the biggest challenges for the program, due to the program's small staff size. Engaging supervisors to be proper mentors was also challenging. Staff further highlighted the need to develop curriculum and learning activities that better link to skills needed for employment opportunities. Finally, high program attrition was correlated with low engagement throughout the whole program, with some staff mentioning approximately 50% of the enrolled learners not responding to their emails nor participating in the synchronous activities.

3.4 ELOs: supervised internships, self-guided projects, and job search

In 2022, 30 learners completed internships (18 as part of the GAP [13]), 25 worked on projects, and 10 focused on seeking full-time employment. The ELOs allowed learners to improve human skills such as communication, teamwork, and remote work. ELOs also helped learners to build a portfolio and improve their technical knowledge in tools and platforms used in the labour market (i.e. Github, Slack). CDS-GAP interns and supervisors were trained by TIG and MIT Bootcamps [13].

- **Supervised internships**

Opportunities: Most internships were remote 24 (80%), 5 (16.7%) hybrid, 1 (3.6%) in-person. Learners felt welcome in the companies. The internship provided learners with a confidence boost in their skills and capabilities and offered professional and cultural experiences. Interns improved their communication, leadership, teamwork, remote work, and relationships skills. Additionally, most internships were good matches and interns highlighted their overall learning value. Some supervisors highlighted the interns' curiosity and eagerness to learn.
Challenges: Some learners were not proactive and relied on program staff to find internship opportunities. Some companies did not involve supervisors in the hiring process, adding challenges to define the internship goals. Moreover, several supervisors were changed throughout the ELOs, affecting the learning experience. Additionally, it was not clear if interns and supervisors codesigned the internship.

- **Self-guided projects**

There was a total of 9 independent and 5 collaborative (of 4-5 learners per group) projects presenting the following results:

Opportunities: Learners got experience in project management, including problem evaluation, ideation, timeline definition and assigning tasks. They used different programming and data science tools and overall improved their portfolio. Collaborative projects promoted interactions across different cultures and improved collaboration skills. The projects provided flexibility to learners with other obligations, like full-time commitments or other studies (e.g. enrolled in undergrad programs).
Challenges: Program staff highlighted the need to improve the pedagogy around the projects, so it better fosters the desired skills. It was hard for learners to define the right scope of projects for a timeline of 3-months. Moreover, connecting learners with technically experienced mentors was not always possible. In the collaborative projects, learners had issues with team management, distribution of tasks to promote equal learning and effort across team members, and proper communication and conflict resolution. Finally, time management was a challenge, especially for learners that had full-time jobs and other responsibilities.

- **Full-time job search**

These learners were seeking to change jobs and decided to focus on finding other full-time employment. The program provided guidelines to report their job search, application, and interviews. At the end of the ELO, learners reported to the program staff that all of them (10) found better jobs.

3.5 Role of mentoring (Na'amal and ELO mentors)

The results suggest having a mentor, who is an expert in technical content and capable of fostering human skills, successfully promotes learning, either in an internship or project. The absence of specific mentors for the self-guided projects made finding technical solutions and dealing with team-related issues (conflict resolution and communication) more challenging. Mentors proved also fundamental for setting clear expectations and reachable goals for the short timeline of the learning experience. Proactiveness and engagement from the learners were determinants of how much value learners could get from mentors.

3.6 Local hubs

Local hubs proved to be key for the success of the overall learning experience. Learners with access to local facilities, events, mentors, and industry contacts more easily adapted and navigated the personal and professional challenges they were exposed to. Moreover, having a local coordinator proved to be essential in the cohesiveness of the local community of peers; and provided support to learners on navigating the local context and finding useful resources for their needs.

Fostering the local hubs is of great importance for the CDS program success given these spaces offer critical nuances regarding the learners cultural and professional environment (unique to each location) that MIT and its initiative have no control over.

4 CONCLUSIONS

This is the first research evaluation of the learning experience for the CDS. Given the diverse background and challenging living conditions of all learners, the program faces several content, pedagogical and technological issues. Nevertheless, learners, internship mentors and staff acknowledge the value of the training activities as well as the support mechanisms put in place to create a community and provide peer support. The program staff see intentional mentoring (seeking the professional and personal growth of the learner) for all ELOs as a key component for the success of the CDS. They also acknowledge finding the right mentors as one of the biggest challenges. Internships are an important component in the program since it directly leads to full-time jobs. The support of the GAP pilot finding internships proved to be fundamental for the mission of the CDS. Considering the program's global reach, it is crucial to contemplate the local context of the learners: local partners are an important pillar that needs to continue being developed. The next step in this research is reconnecting with CDS alumni after six months of program completion to assess its impact in work readiness and full-time job attainment.

5 SUMMARY AND ACKNOWLEDGMENTS

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FROM CURRICULUM TO CAREER: ANALYSING THE CONTRIBUTION OF DELFT UNIVERSITY'S ROBOTICS MSC PROGRAMME TO THE CAREER PATH OF ITS ALUMNI

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ABSTRACT

The increasing global demand for robotics expertise led the Delft University of Technology to launch a two-year Master of Science programme in Robotics in 2020. The programme was designed to educate versatile robotics engineers capable of overseeing the entire process from conception of robotics systems to implementation. The curriculum integrates disciplines such as machine perception, artificial intelligence, robot planning and control, human-robot interaction, and ethics, and emphasises personal development through a course called Portfolio, which was later rebranded as Vision and Reflection. The effectiveness of the programme was evaluated by conducting a survey among the first cohort of students. The online survey, completed by 21 alumni, assessed the programme's alignment with graduates' career paths and their perceptions of the programme. Most respondents (81%) secured employment, with 69% in robotics, and all others had consciously chosen different fields. On average, graduates found jobs in under a month. Common job titles were Robotics Engineer and Software Engineer. However, graduates least appreciated the original Robot & Society and Portfolio courses. The recently rebranded Vision and Reflection course is expected to improve student engagement by focusing on meaningful reflection rather than documentation. Overall, the programme received positive feedback, with 88% of respondents saying it provided a comprehensive robotics education, and 94% stating they would choose it again. However, the evaluation was limited to the more successful half of the cohort, indicating the need to assess the experiences of the remaining graduates, who took over 2.5 years to complete their degrees.

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1 INTRODUCTION

A new two-year MSc programme in Robotics was launched at Delft University of Technology (TU Delft) in the Netherlands in 2020. It was developed as a collaborative effort among professionals, academia, and students, with the aim of training versatile robotics generalists. In this paper, we describe why and how the programme was developed, and present the resulting curriculum. Having welcomed our third cohort of students in September 2022, we are reflecting on our experiences to date and presenting the results of an online survey conducted with the first graduates.

1.1 Why a Dedicated Robotics Programme?

A 2018 study of the Dutch Robotics Industry (Holland Robotics) valued the worldwide robotics market at €22 billion and was forecasted to increase to €50 to €60 billion by 2020 (Berenschot 2018). The study listed five countries—China, Korea, Japan, the USA, and Germany—that accounted for 75% of global robot sales. Europe as a whole accounted for 32% of the industrial market and 63% of the non-military service market.

At that time, the Netherlands was not a major player; Italy, France, and Spain were the strongest in Europe, after Germany. Hence, in 2018, the Dutch Robotics Industry launched an ambitious plan to expand the sector, fuelled by joint investments from the existing robotics industry and the Dutch government. The report also noted that the number of STEM students in the Netherlands is relatively low and that proficient engineering students often choose to study abroad. Furthermore, the report suggested that a partial cause of this situation is the insufficient emphasis on robotics within the educational system. Around the same time, Dutch universities were working on a sector plan on technology (Sectorplan Betatechniek) at the request of the Dutch government. Within this assessment, similar needs were identified and as a result, TU Delft decided to profile and distinguish itself amongst others in the area of robotics.

The above insights laid the foundation for creating a dedicated MSc Programme in Robotics, housed within the faculty of Mechanical Engineering at TU Delft, where robotics was already a research focal point, led by a Cognitive Robotics department. The faculty also oversees the TU Delft Robotics Institute, a university-wide robotics collaboration. In addition to research collaboration, it has previously developed successful educational robotics programmes such as a minor (30 EC) and an honours programme (15 EC), available to students from various BSc degrees offered at TU Delft.

1.2 Curriculum Design and Philosophy

This programme, unlike most MSc programmes that focus on a specific discipline within robotics, aims to train versatile robot generalists, as mentioned above, training them to be creative and to find solutions from different perspectives. This approach originated from the strategic vision of the host Department of Cognitive Robotics, which posits that future robotics engineers will be responsible for guiding society's transition towards increased robotics. Consequently, it is crucial for robotics engineers to receive education not only in a diverse array of purely technical disciplines (qualification) but also in human-robot interaction as well as societal and ethical aspects.

Additionally, to prepare students for a rapidly changing society, a decision was made to include personal and leadership development as key components of the programme, by teaching students to take responsibility for their professional choices (subjectivation) and being able to think critically across cultural and societal contexts (socialisation). The key components—qualification, subjectivation, and socialisation—are based on the educational framework proposed by Biesta (2021).

The curriculum design process implemented the principle of co-creation (Van den Akker (2007), by involving not only academic staff and learning developers but also alumni and MSc students from mechanical engineering working on robotics-related topics, as well as industry representatives. During this process, the development team first defined the societal challenges in the robotics domain, using the Berenschot report (2018) as a reference. Subsequently, a professional profile of the future robotics engineer was created through consultations with the professional field and discussions with students on their desired learning path, and with alumni about what they felt was lacking when they entered the job market.

Next, the team identified the essential technical and professional learning objectives, from which the final qualifications were formulated. These qualifications served as starting points for the collaborative curriculum design process among staff, students, and learning developers. The resulting curriculum design was then shared with and discussed by external stakeholders, including companies, government, and staff from other universities.

1.3 Professional Profile

A robotics engineer possesses knowledge and expertise at the intersection between mechanical engineering and artificial intelligence (AI), and is capable of creating robotics solutions that can perform tasks in complex environments. The focus of robotics lies in the interaction between machines in human-inhabited environments. Although the profile must be viewed as a dynamic entity due to the continuous and rapid developments within the field of robotics, it was determined that a robotics engineer is involved in: 1) understanding how applications function in practice; 2) translating social issues into intelligent machine solutions in complex, multi-dimensional situations that consider ethics, safety, and sustainability; 3) staying up to date on technical developments in robotics and AI; 4) researching, developing, implementing, and testing AI for mechanical engineering systems to improve learning and interaction with their environment; 5) developing mathematical models (perception models, behavioural models, situation analyses, etc.); 6) conducting physical modelling; 7) programming and developing intelligent software for mechanical engineering systems; 8) advising businesses, government, and society on future choices and steps concerning the use and development of robotics; and 9) managing information from sensors and integrating them into complex robot solutions.

The final qualifications of the programme reflect this professional profile and are also in line with the criteria for engineering degrees in the Netherlands, as defined by Meijer et al. (2005) in their translation of the Dublin Descriptors into the Dutch Engineering Education domain. The final qualifications are listed in Appendix A.

2 ROBOTICS CURRICULUM

Based on the principles and processes described above, the curriculum was designed with four connected didactical goals:

1. To provide students with an understanding of the development of intelligent robots and vehicles that will advance mobility, productivity, and quality of life, firmly rooted in theory and with a focus on applications;

2. To train students in handling the entire process of innovative and sustainable designing, operation, and use of robots, as well as computer systems for their control, sensory feedback, and information processing;
3. To guide students in performing research on robotics topics at an academic level;
4. To teach students to operate in complex and multifunctional environments, assuming various roles and developing transferable skills.

The programme is designed for students with a background in mechanical or aerospace engineering who are interested in further developing their skills in robotics beyond technical knowledge. Its objective is to produce graduates who possess an understanding of the global context in which they operate and the capacity to engage with societal issues both as engineers and citizens (Turns et al 2014 and Niever et al 2020).

2.1 Programme Overview

The resulting two-year 120 EC curriculum, which consists of a mix of lectures, team projects, and individual assignments, is shown in Fig. 1. The programme consists of a number of core courses stacked in the first half of year 1 that provide a solid background in Robotics (qualification – Biesta 2021): Robot Dynamics & Control, Machine Learning for Robotics, Robot Software Practicals, Machine Perception, Planning & Decision Making, and Human Robot Interaction, In addition, the course Robot and Society, focusing on the ethics of technology in general as well as on the ethics of robots and AI, form part of the core programme.

In the second half of Year 1 and the first part of Year 2, students are given more agency over their learning when selecting their electives. Students are given the opportunity to practice their preferred roles in the field of robotics in the context of the Multidisciplinary Project. In this course, students work in self-steering teams of 4–5, designing a functional robot for a real customer (socialisation).

Fig. 1. Programme Overview of the MSc Robotics Programme

Students continue focusing on their individual development and preferences in the first quarter of year 2 by completing a 15-EC internship in a company, an internal research assignment, a joint interdisciplinary project (Klaassen et al 2022), or in-depth courses. The students' choices will depend on their developed vision, which they previously presented in the Vision and Reflection course. In line with that, students continue with a literature study (10 EC) and their final thesis (35 EC) on a topic of their choice.

2.2 Reflective Engineer

To train students in reflection, students practice their reflection skills and learn to set personal development learning goals in the course 'Portfolio', subsequently rebranded as 'Vision and Reflection' alongside the technical courses from the start. This course was developed to facilitate informed decision-making, personal development, and career planning for students pursuing their degrees (subjectivation). Within designated groups, students are guided by experienced mentors creating a safe atmosphere for collaborative learning and examination of the impact of reflection, offering opportunities for students to make and learn from errors.

During this course, students set their own personal development goals and, based on those goals, make choices in the individual part of their curriculum to help them reach those goals. Students have to select at least one relevant elective in the disciplines of humanities and social sciences domain to expose Robotics students to related relevant disciplines and help them develop their desired transferable skills. Examples are courses in logistics, cultural differences, regulations, production processes, sustainability, design, economics/business, or (project) management.

Many of the core courses also include reflective-engineering elements. For example, in the course Machine Learning for Robotics, students collaborate and coordinate with a lab partner on coding and reporting tasks, while in Robot Software Practicals, group work is performed and peer evaluation of coding work is included. In the aforementioned multidisciplinary project, students reflect on their team roles and their robotics specialist roles, and the impact their robot may have on the envisioned customers and society (Van der Niet et al 2023). In addition, based on their personal goals students must select at least one robotics elective; and have the freedom to select the remainder of their elective space for general elective choices, enabling students to immerse themselves in other subjects and further enhance their multidisciplinary profile.

With this combination of active reflection, relevant courses in the field of engineering, humanities, and social sciences (in which transferable skills are both implicitly and explicitly present), and student agency in personal goal setting, this programme is the first engineering MSc programme within TU Delft to exhibit an explicit emphasis on personal leadership development for students.

3 INITIAL EXPERIENCES

The new Robotics MSc was launched in September 2020 with an inaugural cohort of 102 students. Among them, 69 were from BSc programmes at our own university (mainly Mechanical and Aerospace Engineering), 11 from other BSc and BEng programmes in the Netherlands, and 22 from abroad. Enrolment in 2021 increased to 118 students, with a peak in international admissions (31), and in 2022, 90 students began the programme. As of 16 April 2023, 47 out of the 102 students who started have graduated, a success rate of 46%. This is on par with the average for the 2020 cohort within our university as of 1 May 2023, and it exceeds the average of all MSc programmes offered by the Mechanical (35%) and Aerospace Engineering (32%) faculties. This number is indicative that the programme in its first run is already quite well aligned, although higher success rates are aimed for.

3.1 Experiences with Personal Leadership Development

The implementation of reflective engineering involved a learning phase, during which the programme received feedback from students, faculty-level organisations, and other stakeholders. A crucial lesson learned was that ‘reflection’ should engage students in meaningful contemplation, rather than mere documentation or portfolio production. This observation was predominantly based on feedback from students and observations of the course coordinators. Specifically, it appeared challenging to engage students through writing activities (which were often postponed until the last possible moment); on the other hand, presentations in mentor groups and gatherings received positive feedback from both students and mentors, including initially skeptical students.

Consequently, in 2021, the Portfolio course transitioned from group sessions and a portfolio form, to just group sessions while incorporating more student mentors in the form of second-year MSc students. While this change led to some improvements and a reduction in workload, in 2022, the management proceeded further by eliminating all formal deliverables, except for active participation, in accordance with the reflective engineering principles (Hermsen et al 2022). In the renamed course ‘ Vision and Reflection’, PhD students and senior MSc students facilitate reflective sessions in small groups during the first semester of Year 1, enabling students to work toward their personal learning objectives and discover their professional identities.

3.2 Industry Feedback

To maintain alignment with the needs of the robotics field and preserve educational collaborations within the professional domain, the programme management conducts quarterly meetings with the professional advisory board. At the latest meeting, one industry representative remarked that the generic capabilities of robotics graduates serve as a unique selling point, stating, ”*pure programmers get stuck because they do not understand the physics of robotics, and mechanical designers get stuck because they do not understand what the robot does.*” A second representative underscored the breadth of Robotics graduates, making them versatile and broadly employable. A third representative also emphasised the growing necessity for process-oriented thinking in Robotics engineers.

4 ALUMNI RESEARCH

As the first cohort of students graduate and transition into the workforce, it is crucial to assess whether the programme’s goal of producing versatile robotics engineers has been met, by gathering feedback from the initial alumni. Garnering insights from alumni is a well-established method for curriculum evaluation (Saunders-Smits and de Graaff 2012).

4.1 Research Question and Methodology

The primary research questions guiding this investigation included: Did the alumni consciously choose to pursue careers in the robotics field? If so, why ? If not, why not? What insights can be gleaned from alumni feedback and perceptions concerning the MSc Robotics Programme?

Following the acquisition of ethical approval, an online survey was administered on April 19, 2023, to all alumni who had graduated by April 16, 2023, using email or LinkedIn connections maintained by staff members. A follow-up reminder was sent one week later. Out of the 47 graduates, 44 were successfully contacted, and out of them, 21 participated in the survey of which 16 completed the entire survey. This yielded a 45% response rate, which is considered high for online alumni research (Lambert and Miller 2014) and is in line with earlier alumni studies at TU Delft (Saunders-Smits and de Graaff 2012).

4.2 Employment

Out of the 21 respondents, 16 were employed, 1 was employed as a PhD student, and 4 were not employed. Of the first category, 69% (11 out of 16) reported that they are currently working within the field of robotics. Of those not working in robotics, none expressed a desire to do so, citing reasons such as low salary potential and a lack of interest, although 80% (4 out of 5) still retained an occupation within the wider engineering sector. On average, it took respondents less than a month (M = 0.89, SD = 1.20, n = 14) to find a job after they completed their degree. Common job titles include robotics engineer (n = 4), software engineer/developer (n = 5), as well as data scientist/analysist (n = 2). Many alumni are employed in industries that use or produce robots, or engage in robotics and AI-related intelligent software solutions.

Of those who are unemployed (n = 4), two alumni reported difficulty finding jobs due to a significant skill gap between their education and industry requirements, as well as a reluctance to hire non-EU or non-Dutch speaking graduates. Thus, finding the ideal combination of a work culture in the high-tech industry and the niche nature of robotics in the Netherlands presents challenges. Graduates may struggle to compete against specialists in software and mechanical engineering roles. The other two alumni were actively seeking specific positions and acknowledged that this process requires time.

Graduates expressed satisfaction with their first job, with 13 out of 14 (93%) answering 'Yes' to the questions: 'Does your current place of employment match the expectations you had for your first job at graduation?' and 'Does your current role match the expectations you had for your first job at graduation?' (Response options were: Yes, No). When asked in a free-response item about the parts of their career they enjoy the most, a common theme of working with robots and real-world systems emerged. Conversely, respondents were most disappointed with the high number of meetings, slow processes, and the necessity to adapt to the software and resources available within their organisation.

4.3 About the Programme

In response to the question of whether the MSc Robotics programme provides a comprehensive view of the field of Robotics, 83% (15 out of 18) of respondents affirmed this. In a follow-up free-response item, they cited the breadth of the program, from perception to dynamics to planning, as a key factor. However, some respondents felt the program lacked in certain areas such as hardware/systems engineering and control.

Furthermore, 94% (17 out of 18) would choose the Robotics programme again if given the chance. The reasons for this choice varied, with some citing their interest in the field of robotics and the focus on software in the programme. Others appreciated the opportunity to apply knowledge into practice. However, one respondent noted the difficulty in securing a job in the current tech industry recession. Similarly, 88% (15 out of 17) would recommend the programme to prospective MSc students. The reasons included its focus on software, good organisation, quality of teaching, and the opportunities it provides for personal development.

Furthermore, responses gave feedback on two points: what additional learning they would have liked from the program, and what new engineering courses they think should be included in the curriculum. Their main ideas were that they wanted more training in technical software, particularly for cloud-based and production environments. They also wished for more in-depth knowledge in systems engineering and mechatronics, a greater focus on how to integrate hardware, and stronger skills in control theory and the structure of machine learning pipelines.

When asked what personal development experience they would suggest adding to a future curriculum, key themes that emerged were a reduction in personal development courses, a focus on practical skills such as evaluating oneself for job interviews and understanding job requirements, and the importance of multicultural collaboration and awareness.

When asked about the most useful aspects of the programme, respondents cited the development of critical skills such as coding and problem-solving, the practical application of these skills in lab assignments and projects, and the comprehensive knowledge foundation provided by the program, particularly in areas such as machine learning, deep learning, and ROS (i.e., Robot Operating System, a widely used open-source framework for building and managing robot software). Conversely, when asked about the least useful aspects of the programme, two courses emerged: Robot and Society (n = 6) and Portfolio (n = 5). On the other hand, one respondent remarked that he loved the reflective engineering concept of the programme.

Four out of 16 respondents (25%) reported having completed the programme in 24 months or less, while the remaining 12 (75%) reported 25–30 months. Inquiries about which parts of the MSc Robotics programme took longer than the nominal duration yielded the following responses: the thesis project (n = 11), the literature study (n = 4), combining study with other activities (n = 4), and the internship (n = 3). This is in line with earlier results of an internal survey that indicated that a primary reason for study delay involved a conscious decision by the student.

Finally, in response to the question regarding gender, all 16 respondents identified as male. When asked about the location of their Bachelor degree, the majority (56%) completed their degree at TU Delft. 38% completed their degree outside the EU, while 6% completed their degree elsewhere in the Netherlands.

5 FINAL REMARKS

In summary, the findings about the new Robotics programme are favourable, and the feedback from students, graduates, industry representatives, and the faculty provides opportunities for continuous programme development. It remains to be seen whether the modifications to the Vision and Reflection course will yield positive outcomes. A more in-depth evaluation of this component is needed. Additionally, further investigation and analysis are required to address the delays within the programme and the unpopularity of the ethics course. It is important to note that the alumni survey results are based on only half of the cohort. All of these respondents completed their degree within 2.5 years and are likely the more successful portion of the cohort. Consequently, it is essential to monitor the progress of the portion of the cohort that requires more time to graduate.

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APPENDIX A: FINAL QUALIFICATIONS OF THE MSC ROBOTICS

1. Competent in the scientific discipline Robotics
A graduate in Robotics is able to…
1A. …acquire and apply broad knowledge on Robotics on the multidisciplinary intersection of mechanical engineering, Robotics and artificial intelligence, more particularly in dynamics, system identification, modelling, control, machine learning, machine perception and human-robot interaction.
1B. …model, design and control robotic systems.
1C. …analyse, evaluate and validate robotic systems in complex environments.
1D. …relate scientific knowledge to robotic systems, critically considering their interaction with societal aspects.
2. Competent in doing research
A graduate in Robotics is able to…
2A. …study a topic by critically selecting relevant scientific literature.
2B. …generate innovative contributions in developing intelligent machines.
2C. …write a scientific report about own research.
2D. …measure, model, and explain the interaction between humans and intelligent machines.
3. Competent in designing
A graduate in Robotics is able to…
3A. …develop mathematical and physical systems using state-of-the-art knowledge.
3B. …translate complex multidisciplinary research to working robotic designs.
3C. …design algorithms and software for complex robots.
3D. …design interfaces for human interaction so that a robotic system's functionality can be understood, taught and corrected by users.
3E. ….design robotic systems which can move safely and efficiently in human-inhabited environments.
4. A scientific approach
A graduate in Robotics is able to…
4A ….contribute novel techniques on the intersection between mechanical engineering, systems and control, and artificial intelligence.
4B. …analyse and design multidisciplinary solutions using system identification, modelling, and simulation.
4C. …solve technological problems in a changing environment, considering ethics, safety, ambiguity, incompleteness and limitations.
4D. …effectively lead, co-create and collaborate with a research team.
4E. …design and perform experiments to compare, investigate, evaluate and test different robotic solutions across disciplines.
5. Basic intellectual skills
A graduate in Robotics is able to…
5A. …develop a vision for applying robotics to address industrial and societal needs.
5B. …consider the design of robotic systems from economic, social, cultural and ethical perspectives.
5C. …critically reflect on own role in projects, in relationship to that of others.
5D. …remain professionally competent with an eye for the needs in the field.
6. Competent in operating and communicating
A graduate in Robotics is able to…
6A. …work both independently as well as in a multidisciplinary team
6B. …operate and communicate in a responsible, ethical and transparent manner, with an open-minded attitude.
6C. …explain and defend research activities and outcomes to academia and industry, both specialists and non-specialists.
6D. …understand and explain robotic systems in relation to other fields.
6E. ...advise on technical steps towards integral robotic solutions in complex environments.
7. Considering the temporal and social context
A graduate in Robotics is able to…
7A.… consider the limitations and possibilities of applying robotics to solving safe technological and societal problems.
7B. …evaluate and assess the technological, ethical and societal impact of one's work.
7C. …act with vision in an interconnected and rapidly changing world.
7D. …act with integrity and responsibility regarding sustainability, safety and privacy, and economic and social wellbeing.

Draw education: graduate student perceptions of education using an arts-informed approach

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Keywords: arts-informed approach, critical pedagogy, disciplinary difference, graduate education

ABSTRACT

Education has been shifting to foster better learning environments for students with instructors as co-constructors of knowledge in the classroom. Part of this educational transformation has been accomplished through graduate student education in preparing the next generation of educators to adopt student-centered teaching approaches. Change, however, can be slow, and implementation in the classroom looks different across disciplines. The purpose of this study is to gain a better understanding of graduate students' perceptions of education when enrolled in a course on contemporary pedagogy. We seek to answer RQ: How do perceptions of education compare between graduate students in engineering and non-engineering academic disciplines? Arts-informed approaches provide an avenue to understand student perceptions and allow students to express their ideas in a creative and non-traditional way. For this study, we gathered drawings from 38 graduate students from multiple disciplines enrolled in a graduate-level course on contemporary pedagogy. Data were analyzed to compare disciplines along the spectrum of concrete, active, reflective, and abstract. Results from pre-course drawings indicate a breadth of student expressions and perceptions of education, including metaphors and discipline-specific content. Students draw on their prior experiences, but also look to the future in how they envision education to be. Themes include education as: an active- learning approach, cognitive development, futuristic, a global endeavor, knowledge acquisition and transfer, lecture-based, metaphors for education, and influence from personal experiences. Future work will include analysis of post-course drawings and reflections to gain a full understanding of how the course impacted students' perceptions of education.

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1 INTRODUCTION

Despite calls to promote innovation and creativity, engineering continues to struggle with how to prepare engineers to face engineering challenges for a more sustainable future (Murzi et al. 2016). The National Academy of Engineering (NAE 2018) recognizes creativity and design as essential skills for the engineering profession and there is an expectation that the field will drive innovation and technological developments, which overall will improve economies. Yet, engineering education is still shifting from rigid, lecture-based teaching approaches to more culturally responsive, student-centered pedagogy. Part of the issue is often attributed to cultural traits of the engineering field—often characterized as masculine, individualistic, and function-oriented (Dryburgh 1999, Faulkner 2015, Henwood 1998, Tonso 2007). The discipline has also been described as having a "hostile environment" (Zongrone et al. 2021), especially for marginalized groups and those who do not fit the dominant culture of engineering. Hence, this culture can reinforce destructive perceptions of education for students, with an excessive focus on grades, finding the "only right answer" to test questions, and rote memorization (Tonso 2006) - which do not necessarily connect to learning. Learning theories emphasize that students thrive in environments where they feel valued, psychologically safe, and free to express their ideas (Ambrose et al. 2010, Ormrod 1999).

Perceptions of education may look differently depending on the student, their background, and the culture in their academic discipline. Some disciplines outside of engineering may perceive education differently (e.g., focus on constructing knowledge rather than memorization) which can influence how they learn and impact their perceptions of education and on developing innovative thinking and creativity. It is through intentional educational pedagogies that we can develop creative and innovative engineers not at the expense of its discipline-specific technical knowledge and problem-solving skills. One way to bring change to the next generation of engineers is through graduate student education, as some students become faculty members and bring contemporary pedagogical practices to the classroom. By preparing the future faculty members in charge of training the next generations of engineers, we can have a long-term impact to change the culture of engineering and engineering students' perceptions of education. As expressed by (Freire 1996):

> Education either functions as an instrument which is used to facilitate integration of the younger generation into the logic of the present system and bring about conformity or it becomes the practice of freedom, the means by which men and women deal critically and creatively with reality and discover how to participate in the transformation of their world.

While education has been shifting to foster better learning environments for students with instructors as co-constructors of knowledge in the classroom, implementation in the classroom looks different across disciplines. Thus, the purpose of this study is to gain a better understanding of graduate students' perceptions of education based on their disciplinary backgrounds when enrolled in a course on contemporary pedagogy. We seek to answer the following research question:

RQ: How do perceptions of education compare between graduate students in engineering and non-engineering academic disciplines?

1.1 Arts-Informed Approaches

To respond to our research question, we took an arts-informed methodological approach. Arts-informed methods in engineering education research have been used to obtain valuable perspectives and insights not evident in traditional data collection approaches. Engineering is often seen as a discipline focused on technical aspects, but incorporating arts-based approaches can help bridge the gap between technical knowledge and creative expression. By integrating artistic practices, such as drawings, researchers can tap into the visual and imaginative dimensions of learning, enabling students to explore and communicate their understanding of concepts in new ways. Arts-informed approaches have been used in higher education to understand student perspectives both in engineering and non-engineering disciplines. For example, it has been used in engineering education to gain deeper insights of engineering identity development and of first-year students' perceptions of engineering with 'draw an engineer' and 'what is engineering' activities (James et al. 2020, Murzi et al. 2022). These studies used this approach to understand both disciplinary differences and institutional differences through student comparisons and institutional first-year course comparisons. Visual inquiry through freehand drawings has also been used in academic disciplines such as business and political science (Page and Gaggiotti 2012, Donnelly and Hogan 2013). In this study, arts-informed methods are used to understand student perceptions of education and explore disciplinary differences between engineering and non-engineering students.

2 CONCEPTUAL FRAMEWORK

This study takes a stance on education and understanding student perspectives using critical pedagogy and a framework on disciplinary differences. (Bradbeer 1999) uses Kolb's experiential learning theory to conclude that "different disciplines both process and structure knowledge in different and distinctive ways." (p.384-385). Thus, disciplines can be defined along a spectrum of abstract-concrete and active-reflective. For example, Sociology and English are considered concrete and reflective disciplines, while Engineering and Business are considered abstract and active. The orientation of academic disciplines along this spectrum is shown in Figure 1. These disciplines can be further broken down to convey disciplinary differences in engineering.

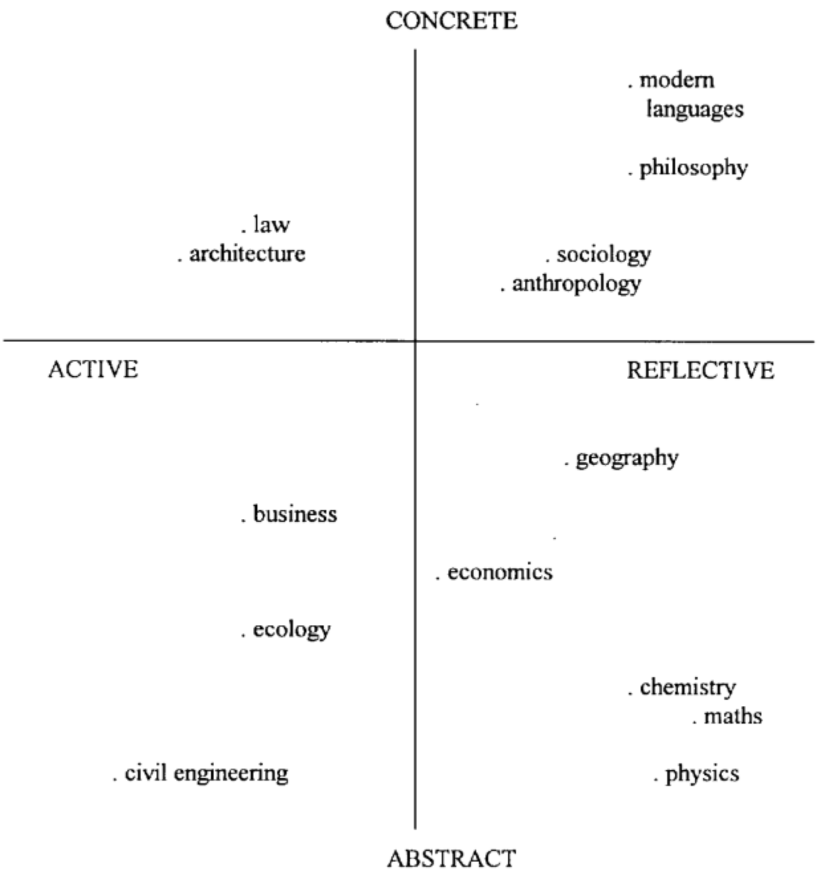

Figure 1: Academic discipline orientations (Bradbeer 1999).

3 METHODOLOGY

This exploratory, qualitative study was conducted in a graduate-level course at Virginia Tech, which is a large, research-focused public university in the U.S. Arts-informed approaches provide an avenue to understand student perceptions and allow students to creatively express their ideas in a non-traditional way.

3.1 Population and Data Collection

For this study, we gathered drawings from 38 graduate-level students from multiple disciplines enrolled in a graduate-level course titled GRAD 5114: Contemporary Pedagogy. A breakdown of the academic disciplines of students in the course categorized as engineering and non-engineering are shown in Table 1. Additionally, of the 38 students, 27 students were doctoral-degree seeking and 11 were masters-degree seeking at the time of course enrollment. Student demographic information was collected but not utilized for analysis in this study.

Table 1. Academic disciplines breakdown by engineering and non-engineering

Categorization	Discipline	Frequency	Total
Engineering	Aerospace Engineering	1	15
	Biomedical Engineering	1	
	Civil Engineering	3	
	Engineering Education	4	
	Engineering Mechanics	1	
	Industrial & Systems Engineering	2	
	Mechanical Engineering	3	
Non-Engineering	Architecture	1	23
	Biological Sciences	4	
	Biomed & Veterinary Sciences	1	
	Chemistry	1	
	Communication	1	
	Curriculum and Instruction	3	
	Educ Ldrshp & Policy Studies	1	
	English	2	
	Entomology	1	
	Environmental Design & Planning	3	
	Fisheries & Wildlife	1	
	Forestry	1	
	Geosciences	1	
	Planning, Governance, & Global	1	
	Public Health	1	

On the first day of the course, students were supplied with paper and drawing materials and were prompted to "Draw Education." Some students used paper and pencil, while others used digital mediums. Students submitted their drawings as .jpg, .png, or .pdf files.

3.2 Drawings Analysis and Limitations

Drawings were coded both a priori to compare disciplines along the spectrum of concrete, active, reflective, and abstract, and openly, using thematic analysis. We followed the six-phase process of thematic analysis outlined by (Braun and Clarke 2006), which includes 1) becoming familiar with the data, 2) generating initial codes, 3) searching for themes, 4) reviewing themes, 5) defining and naming themes, and 6) reporting themes using selected excerpts (in this case drawings). As part of this process, a codebook was developed that included initial coding, definitions of codes, example drawings, final themes, and mapping onto disciplinary orientations. Themes were examined for any patterns emerging in comparison between engineering and non-engineering disciplines.

Data limitations include the context of the research site, which may not account for the cultural and personal backgrounds of the graduate student participants enrolled in this course on pedagogy in the U.S. This work could be expanded to compare drawings from institutions across culturally diverse contexts to compare disciplinary differences. Although an arts-informed methodology is used intentionally to gain a deeper understanding of student perceptions of education, it also has limitations. While drawings provide a non-traditional medium for students to express their ideas, analysis of student drawings are limited by the interpretations of the authors. "Art is in the eye of the beholder" - in this case the researchers, which may not accurately represent student interpretations and intention since drawings were not accompanied by a description or explanation. Furthermore, drawing representations only consider current graduate academic disciplines and do not account for students' undergraduate education disciplinary backgrounds, which could impact the representation of ideas and mapping onto the disciplinary orientations.

4 RESULTS

Results from analysis of drawings from the first day of the course indicate a breadth of student expressions and perceptions of education. For example, a comparison of student perceptions from lecture-based to active-learning approaches in the classroom are shown in Figure 2.

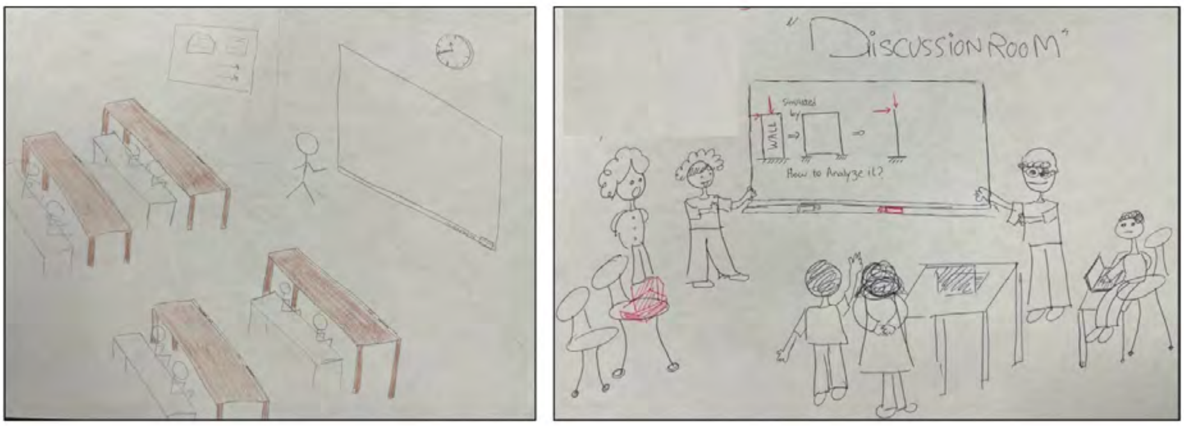

Figure 2: Lecture-based and active-learning drawing examples.

Themes that emerged from drawings analysis include: active-learning approaches, cognitive development, futuristic, global perspective, knowledge acquisition and transfer, lecture-based, metaphors for education, and personal experiences. These themes and their definitions and codes are shown in Table 2 and varied from concrete to abstract and by engineering and non-engineering disciplines.

Table 2. Codebook with themes, definitions and abstract-concrete orientation.

Theme	Codes	Definition	Orientation
Active-learning approaches	Applying knowledge Co-construction of knowledge Discussion	Encompasses active learning approaches with communication and discussion in the classroom	Concrete
Cognitive development	Brain Light bulb	Focus on cognitive thoughts and the brain	Concrete / Abstract
Futuristic	Advancing technology First day of school Growth mindset	Looking towards the future; focus on growth and/or technology as a component of education. Also focus on making a difference and the world a better place	Concrete / Abstract
Global endeavor	Earth/Globe	Perspectives of education as a global endeavor and impact across the world	Abstract
Knowledge acquisition and transfer	Books Communicating ideas Transfer from one generation to the next	Focus on acquisition of knowledge and transfer of knowledge through communication via people or books	Concrete
Lecture-based	Classroom setup Instructor	Traditional views of the classroom, instructor hierarchy	Concrete
Metaphors for education	Garden Time process Tree	Metaphors that are used to describe education or the process of education	Abstract
Personal experiences	Discipline-specific Hobbies Lived experiences Personal interests	Includes the personal interests and connections that students bring to their educational experience.	Concrete

Some select themes are shown in Figure 3, including knowledge acquisition and transfer, metaphors for education, and global endeavour.

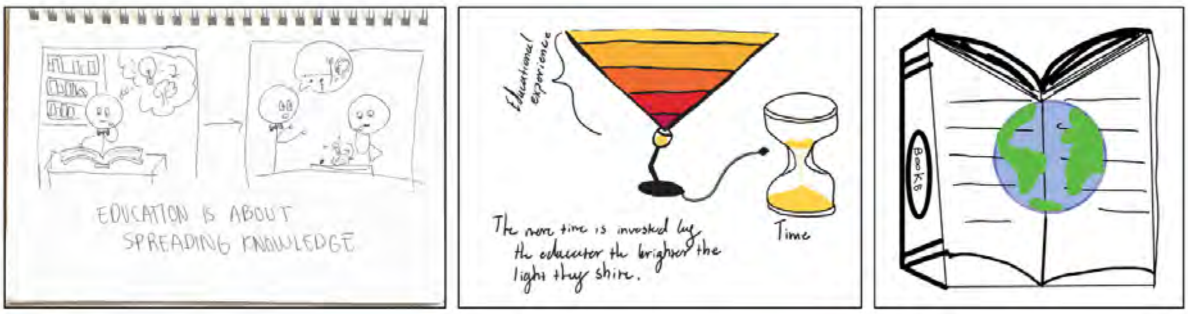

Figure 3: Knowledge transfer, metaphors for education, and global endeavour themes.

The knowledge acquisition and transfer example shows a drawing of a person reading a book and then explaining to another person with the caption "Education is about spreading knowledge." Two other examples in Figure 3 show education as a metaphor with a caption that says "the more time is invested by the educator, the brighter the light they [the student] shine" and education as a global endeavor with an illustration of a globe on a book.

Drawings in the cognitive development theme varied by discipline, with contrast between engineering and non-engineering disciplines. Cognitive development included drawings of the brain with variation between abstract and concrete. Engineering discipline perceptions of education in the cognitive development theme were concrete (as shown in Figure 4), while non-engineering discipline perceptions of education were abstract (as shown in Figure 5).

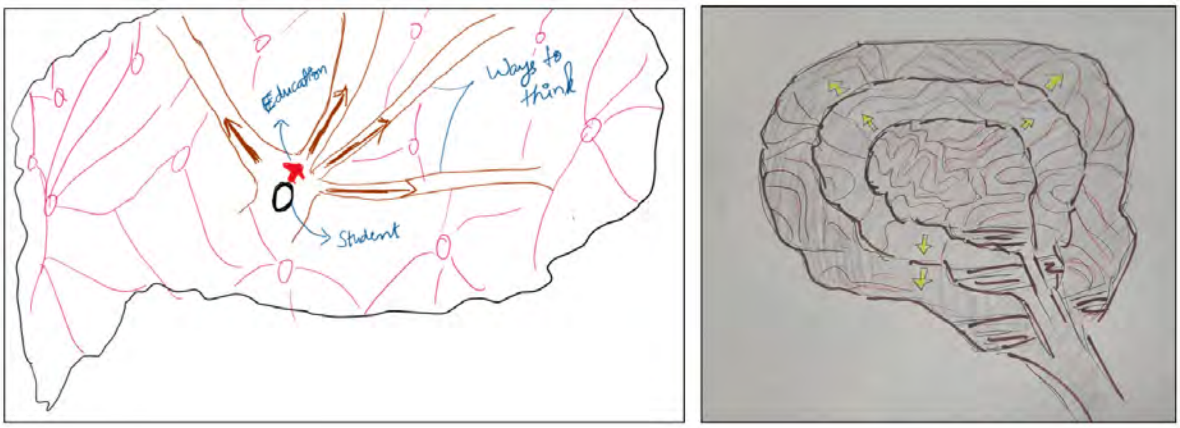

Figure 4: Engineering discipline drawings in the cognitive development theme.

The non-engineering disciplines that included more abstract perceptions of education as cognitive development were English, Chemistry, and Public Health.

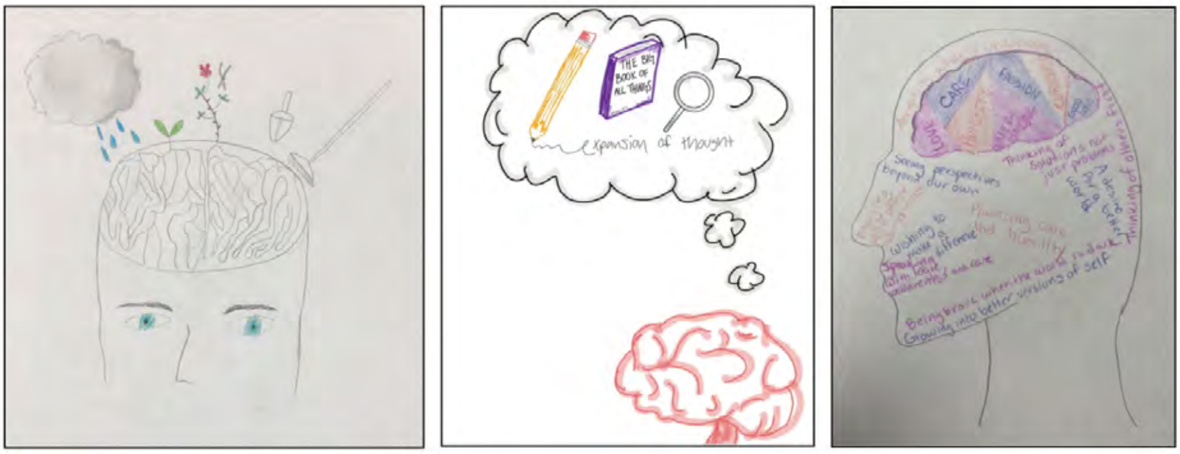

Figure 5: Non-engineering discipline drawings in the cognitive development theme.

5 DISCUSSION

Understanding graduate student perceptions of education is a critical first step for the transformation of our educational systems with contemporary pedagogical practices. It is important to note that student perceptions of education may not be explicitly or wholly expressed through student drawings, however, there are some notable interpretations between disciplines. We do not wish to define or stereotype students by their academic disciplines. While some disciplinary differences emerged, this did not include detailed analysis of individual differences within disciplines or separation of engineering disciplines. Students drew on their prior experiences to represent education and included traditional lecture-based views of the classroom with the instructor at the front and students in rowed desks, while others drew more discussion-based and co-learning environments. Although this paper did not include the full analysis of individual student perspectives of education, overall, a majority of engineering disciplines captured concrete experiences, while non-engineering disciplines expressed their views more abstractly. This is shown for example when comparing the cognitive development theme between engineering and non-engineering students in Figure 4 and Figure 5. This is opposite of what would be expected from the disciplinary orientations shown in Figure 1. It should be noted that these disciplinary differences developed by (Bradbeer 1999) focuses on learning and may not capture the way students creatively express themselves or their views on education in their respective disciplines. Furthermore, this framework may look different based on cultural contexts, and this study does not take into consideration the cultural and academic background of the graduate students who participated in this study. A study by (Ubidia, Guerra, and Murzi 2022) considers the differences between architecture and civil engineering students. An understanding of disciplinary and cultural differences is important for educational strategies to better prepare students to collaborate and communicate across these disciplinary divides.

Additionally, it should be noted that this arts-informed approach can be used as both a pedagogical tool and as a research methodological component. In the classroom, it is used to engage students in critical thinking and interpretation of self and others' perspectives. Students also co-construct knowledge as they see, interpret, listen and learn from their peers and can also gain a better understanding of education through the eyes of their peers.

6 CONCLUSION

Arts-informed approaches provide an avenue to understand student perceptions and allow students to express their ideas in a creative and non-traditional way. For this study, we gathered drawings from 38 graduate-level students from multiple disciplines enrolled in a graduate-level course on pedagogy at Virginia Tech. Data were analyzed to compare disciplines along the spectrum of concrete, active, reflective, and abstract and identify themes across disciplines. Drawings indicate a breadth of student expressions and perceptions of education, including metaphors and discipline-specific content. Students draw on their prior experiences, but also look to the future in how they envision education to be. Some themes include education as: a global endeavor, lecture-based, social interaction, processes, cognitive development, making a difference, active-learning, and influence from personal interests and experiences. This work demonstrates the richness of non-traditional research methods such as arts-informed approaches for gaining a deeper understanding of student perspectives.

7 FUTURE WORK

This work is only in its initial steps in uncovering student perspectives of education and there is more left to be done. Through co-construction of knowledge together with students, we can gain a deeper understanding of their perceptions of education. Thus, this work will be expanded to include student reflections alongside the drawings to improve interpretation of students' expression of ideas. Future work will also include analysis of post-course drawings and reflection data to gain a full understanding of how the course impacted students' perceptions of education. By comparing pre-course and post-course drawings, we can also gain insight into how graduate students' perceptions of education evolve through the course. "Looking at the past must only be a means of understanding more clearly what and who they are so that they can more wisely build the future." (Freire 1996)

8 ACKNOWLEDGEMENTS

We would like to thank our incredibly passionate graduate students in this course for their insightful discussion and participation as co-constructors of knowledge in our classroom.

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IMPACT OF TEACHER TRAINING ON ENHANCING SUSTAINABILITY INTEGRATION INTO ENGINEERING EDUCATION

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Keywords: *Sustainability education, sustainability in curricula, sustainability integration, pedagogical training, impact evaluation*

ABSTRACT

Engineering education institutions face a growing demand to provide graduates with adequate skills to respond to the sustainability crisis at hand. One approach to address this is to integrate sustainability as a cross-cutting theme into programmes and courses. At the same time competence development of academic staff is seen as an essential, yet underdeveloped prerequisite for a sustainability paradigm shift.

Aiming at enhancing sustainability integration into engineering education, this study investigates the impact of pedagogical training on the skills and motivations of teachers to embed sustainability into their teaching. A new pedagogical course (3

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ECTS) on sustainability in teaching was developed and executed at Aalto University four times during 2021-2022. The research data consists of course feedback, written reflection assignments, questionnaires to course participants, and a set of semi-structured interviews with teachers who had completed the training. In the analysis, we utilized an application of the four-level Kirkpatrick model of evaluating training impact. Preliminary results indicate that training is effective, especially when providing hands-on and customized support for teachers with different starting points for sustainability integration, and that both interdisciplinary and field-specific peer-support and learning are important elements of an impactful training. Apart from providing new knowledge on the impact of training on teacher capabilities, the study contributes to the development and improvement of pedagogical support for engineering educators to integrate sustainability into their teaching.

1 INTRODUCTION

1.1 Sustainability integration into engineering education

Sustainability is a hot topic on the agendas of universities and among others, engineering education faces a growing demand to provide graduates with adequate skills to respond to the sustainability crisis at hand. Both current and future engineering professionals will play a crucial role in driving the indispensable changes required to transform our path in sustainable directions. To answer this demand, education for sustainable development (ESD) is a key task for engineering education.

Apart from the common approach of offering sustainability-focused specialized courses for students, another approach to address this task is to *integrate sustainability* as a cross-cutting theme into programmes and courses (Kolmos et al. 2016). The key role of teachers in bringing change in academia (Barth 2013; Thomas 2015) is evident, but also a challenge, as teacher motivation and lack of sustainability-related competencies have been identified as hindrances to implementing ESD (Blanco-Portela et al. 2017). Competence development, through for example specific training of academic staff, is seen as beneficial or even as an essential prerequisite for a sustainability paradigm shift in higher education (Barth and Rieckman 2012). However, training of university teachers in teaching sustainability is found to be underemphasized and insufficient in higher education institutions (HEIs) (Holdsworth et al. 2008; Karvinen et al. 2016; Karvinen et al. 2017). At the same time, previous studies show that pedagogical training in general has a significant impact on the participants in developing as a teacher and in gaining pedagogical understanding, but due to a lack of affirming experiences, the transformative learning process often remains limited (Clavert and Nevgi 2012).

To reach the goal of enhancing ESD in engineering studies, we explore the impact of a pedagogical training course on individual teachers, particularly on their knowledge, skills, motivation for sustainability integration, and the actual implementation of the integration into their field-specific teaching.

1.2 Supporting teachers in sustainability integration

Aalto University's recent strategic goal is to strengthen sustainability throughout its operations. Regarding the development of education, competence development was identified as a key measure and thus, the university has developed teacher training to enhance and support the capabilities and motivation of the teachers to integrate sustainability into their teaching. The 3 ECTS pedagogical training course ("Sustainability in Teaching", SiT) was designed in collaboration with sustainability specialists and pedagogical specialists of the university and has been executed twice a year since 2021. The course is open to all faculty at Aalto University, with a limit of 20 participants at each execution. Priority is given to professors and lecturers on the tenure track.

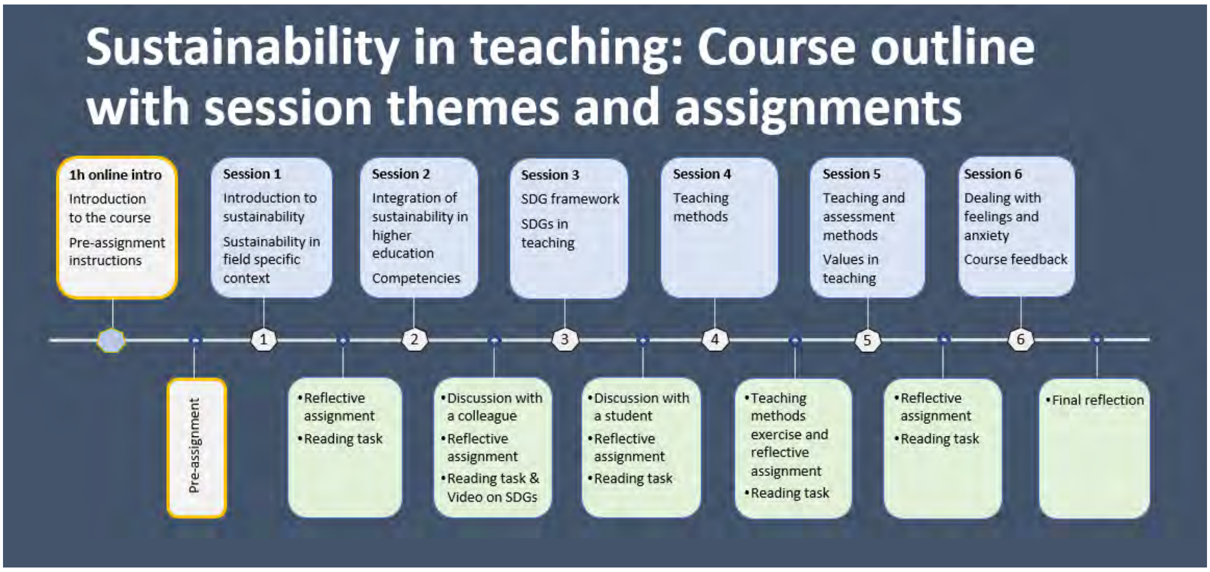

Fig 1. Outline of the SiT-course.

The course consists of an introductory session about practicalities, followed by six bi-weekly sessions (á 3 lessons) covering various aspects of sustainability integration, sustainability competencies, teaching and assessment methods of sustainability-specific competencies, and contents (Figure 1). Additionally, the course addresses the role of values and emotions in ESD. The structure of the course has remained the same since the beginning, but based on feedback some teaching and learning activities have been developed further with an aim to better support teachers with different professional and career stage determined starting points for their teaching.
The sessions are accompanied with advance readings of the newest relevant literature, and the participants are requested to have discussions about sustainability in their field both with department/programme peer teachers, and students. They also familiarize themselves with diverse online learning materials. Between the sessions, the participants work on reflecting and applying the learnings of the session to an actual course they want to develop during the SiT. The aim is that the participants would identify possible ways of embedding sustainability into their teaching and create a feasible plan during the training on how to implement sustainability integration into the course they are teaching, including the design of concrete learning activities.

2 METHODOLOGY

2.1 Analytical framework

In our study, the impact of the pedagogical training is approached through an analytical framework, building on a firmly established model initially developed by Don Kirkpatrick in the 1950s (Kirkpatrick and Kirkpatrick 2005). It’s a method of evaluating training impact and although it has predominantly been designed for and used in the corporate world, it has also been applied in higher education (Cahapay 2021).
The framework captures training effectiveness on four levels, namely:

1) reaction: satisfaction of participants towards the training;

2) learning: measures knowledge, skills, motivation acquired by training participants, and confidence to perform the expected change;

3) behaviour: ascertains changes in behaviours as a consequence of the training, measured by the level of activity following the training; and

4) impact: institutional outcomes that indicate the effectiveness of training.

As we applied the model to the learning for sustainability integration at HEIs, the operationalization of the four levels required some adjustments. In our analysis, the reactions (level 1) are quantitively measured through instant feedback as grades and feedback given for the training by the participants. The learning (level 2) is a qualitative measure, based on the participants' self-evaluation. We are particularly interested in what elements of the training supported the learning of the participants. The behavioural change (level 3) can be observed numerically through the number of teachers who have actually made changes in their teaching in order to integrate sustainability, and how many students have been exposed to it. To have a deeper insight into different types of changes made, a complementary, qualitative approach is useful. The impact (level 4) has been identified as the most difficult to reach. Since higher education follows the temporalities of curriculum cycles, for example, course and programme renewal and consecutive student learning, the analysis of institutional outcomes would require more long-term observation and more versatile methods of study. Thus, we concentrated our analysis mainly on levels 1-3, leaving level 4 as a task for future research.

2.2 Material and methods

Our study material consists of data derived from the three/four first executions of the SiT-course in 2021 and 2022 (Table 1). A total of 75 persons have participated in the courses. As study subjects, we invited course participants who completed the course and are still employed at Aalto University (Table 1). We used data triangulation to allow for the temporally distinct levels of analysis of the applied Kirkpatrick model and the qualitatively different information needs of the analysis (see also Cahapay 2021). Thus, our research material for the study consists of retroactive material, i.e. existing register data (anonymous course feedback, course assignments) and material collected only later specifically for the study purpose (survey, interview). Since tracing the impact of the course requires time between training and actual changes in teaching, the data collection for material other than retroactive material was targeted only at the completers of the three first executions of the SiT, altogether 41 participants.

Table 1. Summary of study material. As the course feedback is anonymous, we have no demographic information on those respondents. Note: Apart from teachers in the engineering field, the SiT-course has been offered to teachers in Business, and Arts and Design. However, only two of the respondents do not represent engineering fields.

	Professor (track)	Lecturer/ Univ. teacher	Other (postdoc)	N	% of invited
Anonymous retroactive study material (participants in 4 course executions)				75	
Course feedback	N/A	N/A	N/A	38	51%
Retroactive study material (invited, from 3 course executions)				41	
Pre-course questionnaire	4	5	3	12	29%
Course assignments	4	5	3	12	29%
Collected material (invited, from 3 course executions)				41	
Post-course survey	4	5	3	12	29%
Semi-structured interview	1	3	3	7	17 %

After data collection, the interview recordings were transcribed and all the data was pseudonymized. For Finnish native speakers, the interview was conducted in Finnish. Where necessary, quotes have been translated into English by the authors. As the course was offered to teachers in engineering, arts and design, and business, we refer to individual respondents accordingly with E= Engineering, A = Arts and design, B = Business, and a running number.

As part of the analysis, the anonymous course feedback and post-pedagogical course sustainability integration activities carried out by the teachers were quantitatively described. For the qualitative analysis, the material was manually coded as inductive coding in Atlas.ti, however, reflecting themes and patterns that were interpreted as relevant regarding the Kirkpatrick model levels of impact (Thomas 2006). At this stage of our study, we relied on single coding. In the following sections, we present selected key results categorized according to the Kirkpatrick levels of analysis.

3 RESULTS AND DISCUSSION

3.1 Reaction to training (Level 1)

In general, the course received very good post-course feedback from the participants (Figures 2 and 3). On a scale of 1-5 (1 the lowest and 5 the highest), the course was graded with a total average of 3,97. Regarding the question about whether the course met the expectations of the participants, 92 % answered that the course either met or exceeded their expectations. When asked, whether they would recommend the course to their colleagues, only one respondent would not recommend the course, while 84 % of the course participants would recommend the course (N = 38). 13 % answered "I do not know".

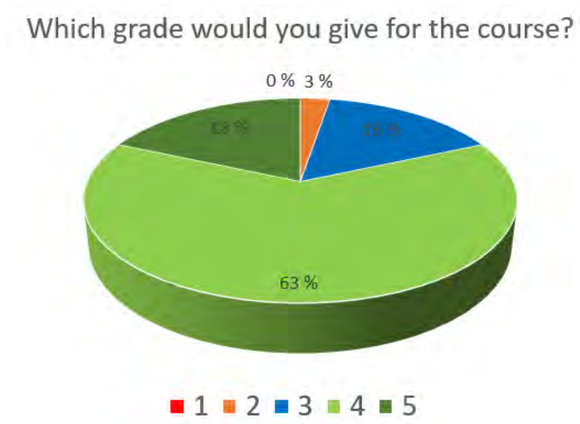

Fig. 2. Participant assessment of the course quality. Scale 1-5 with 1= fair, 5= praiseworthy, N= 38.

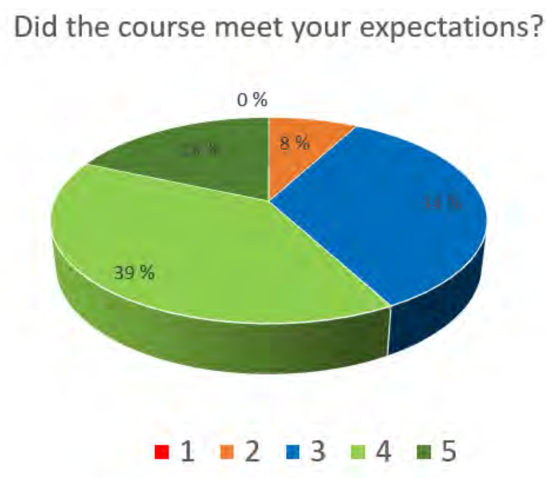

Fig. 3. Participant assessment of course concerning their expectations. Scale 1-5 with 3= the course met my expectations, 5= the course exceeded my expectations, I was surprised, N=38.

3.2 Learning (Level 2)

In terms of participant learning, our main finding was that the course did contribute to their learning. Particularly the collegial discussions supported the learning in a positive way. The learning was pronounced regarding new perspectives and complexity of sustainability, and sustainability competencies as a way to approach integration into teaching. Additionally, the training boosted the confidence of the teachers to actually start integrating sustainability into their teaching.

While the participants mostly had basic knowledge about sustainability, the concept of students acquiring specific sustainability competencies was an *"eye-opener"* (E8) for several participants. As highlighted by one participant: "*Once we started to discuss about teaching methods and sustainability competencies, the learning process really started within me: it is only then when I started to appreciate the true complexity of sustainability in teaching, which means that earlier I have had rather superficial – or one-sided – understanding about it"* (E8). As a part of the learning, the course helped the teachers to challenge their accustomed ways of approaching sustainability. Finding new connections in their subject field seemed to require the nudge to look at their subject from new angles: "*I just realized when I started revising the lecture that it is very easy to link observations […] to sustainability themes, I just need to put "different glasses" on*" (E4). For the teachers in the various fields of engineering, the connections to environmental aspects of sustainability were familiar to a larger extent, but major learning happened regarding the social dimension of sustainability. As one participant stated that "*The course improved my understanding on the importance of social sustainability. Social structures can render our efforts futile and most people do not realize this*" (E9).

Turning their learnings into actual modifications in the teaching through, for example, addressing new sustainability content or exploring new ways of teaching, seemed to require many teachers to step out of their comfort zone. Having been reluctant to do so earlier, several teachers stated after the course that they felt more confident in taking the first steps toward sustainability integration. "*Now, I feel I […] am more ready to discuss about it [sustainability]"* (E8). This included acknowledging that sustainability integration is a process and that it can be advanced piecemeal in small steps. This was an important insight for many. Readiness to start sustainability integration does not mean that one has to be a full specialist, but requires the courage to take the first steps on a journey that will continue: "*I gained confidence to do it, even if I am not in any way specialised on the subject*" (A2).

We attempted to trace in more detail, what supported the learning and confidence-building of the course participants. Our respondents saw collegial peer support through both spontaneous and facilitated discussions as a very important factor in their journey to integrate sustainability. This was evident in several ways and in the analysis, we found three categories in how collegial discussions supported their learning:

a) Sharing of insights: It was widely acknowledged that there exists already a lot of competence and insights within Aalto University, but siloed ways of working prevent this from being usefully deployed for the learning and benefit of all. Apart from seeing sharing as useful in general, it was seen also indispensable for creating a more holistic and systems-level approach, which was considered essential to sustainability education: "*I believe we have many teaching practices in place that are suitable also for educating sustainability. Therefore, I believe sharing best practices will be a must, but also sufficient for providing the necessary toolbox to teachers*." (E1)

b) Widening of perspectives: As a multidisciplinary HEI, Aalto University can provide fruitful ways of broadening one's thinking through encounters with perspectives from other engineering areas, or even disciplines from within Arts and Design, or Business. Facilitated discussions in mixed background groups during the course nudged the participants to think differently than accustomed: "*I liked the most the small group discussions [..] they gave me food for thought and challenged my own thinking.*" (anon. feedback)

c) Encouraging a sense of community: Academic specialists in their specific field often feel that when discussing and integrating sustainability in their teaching, they leave their comfort zone and are insecure about their expertise. Here, peer discussion can act as encouragement and reassure that getting hands dirty with sustainability integration is a joint pursuit and challenge. As highlighted by one participant: "*Most important thing I have learned or seen in this course is definitely that I am not alone with the problems and that there are others to whom I can connect also for help*." (E3)

Our key takeaway is that it is crucial to enable and nourish this kind of collegial support. It requires sufficient time and the creation of an encouraging atmosphere during the training. Even though spontaneous informal discussions could be possible in the academic community, it seems that the time constraints of everyday academic work, and the lack of encounters (especially since the pandemic has increased remote work) are the main hindrances. Thus, allocating sufficient time during the course for these designated discussions is crucial for its success.

3.3 Behavioral change (Level 3)

In our survey and the interviews we asked the course participants whether they had made changes in their teaching to integrate sustainability and if yes, what kind of changes, and how many students have these changes affected.

According to our respondents, since completing the course, altogether an estimated 675 students have been exposed to new sustainability-related teaching. Of these, 461 students were in the field of engineering. As the development of teaching and teacher competencies is a process that evolves over time, it is likely that more changes still will be implemented in the future, since they were still in a preparatory phase. Three respondents reported that they already had a feasible plan, on how to change their forthcoming teaching to integrate sustainability.[2] One participant had made a plan, but due to changes in teaching responsibilities, another teacher actually implemented the changes. As for the implementation, a special mention was the structure of the SiT-course that was considered helpful to the participants in supporting their ability to design and implement changes in their teaching:

"The step by step -structure of the course led me to act and include sustainability into my course. [...] The course helped me to prepare myself and to figure out e.g. which kind of course material I could collect regarding my own field and sustainability, and how to present the assignment subject to the students." (A2)

The analysis gives us more insight on the different strategies and "depth" of sustainability integration, adopted by the teachers. Here, it is important to keep in mind the differences in the situation of the teacher within their specific programme and

[2] In regard to these numbers, it is important to note that our data can be biazed. The small N might indicate that those teachers who had actually made changes were more prone to participate in the study.

position, and hence, their differing “leeway” in implementing changes, or at times, even (re-)creating courses. We identified the following different strategies with increasing depth of integration:

A) Building awareness of and enabling encounters with sustainability: Here, no new content is included, but during classes, the teacher is being more explicit and makes students more aware of already existing sustainability connections and issues. One key was emphasizing and explication of sustainability relevance of the course content, which remained the same: *“Highlighting certain existing elements in my teaching, instead of assuming that students can see the connection.”* (E1)
Another way of increasing awareness was setting sustainability as the context of exercises, such as calculations: “*In the exercises the implementation of the topical subject with sustainability is most simple. Now I could imagine me developing nice calculation examples […] including mass -and energy balances with solubility and liquid/vapour -data or other physics to point out the sustainability issues.*” (E7)

B) Learning activities to explore sustainability connections: Here, the course core content was connected to one or several aspects of sustainability, utilizing frameworks, such as the UN Sustainable Development Goals (SDGs). The course would typically include an introduction to sustainability as new content and the students be given learning activities that would direct them to discuss and explore how the topic at hand is connected to sustainability. As an example: *“I added sustainability and SDG:s as a theme into an independent assignment of […] course”.* (A2)

C) Field-specific teaching with sustainability focus: At this level, the course would revolve around field-specific sustainability connections and engages students to work with these issues in a major coursework or project, typically including teamwork. This type of integration requires a major reallocation of workload during the course in question and means re-structuring many components of the course, including introducing the selected perspectives and facilitating a major learning activity. As an example: “*I added [..] one lecture with sustainability topics (included: the domains, key-performance indicators in relation to social, economical and environmental sustainability of [course topic], feedback loops, normative decisions) and then a larger project work in which students need to create a [board] game.*” (E8)

The processual character of teaching development was evident from our data. One teacher reported minor changes of type B in their first execution of the course but planned to shift into a deeper integration (type C) in the next execution of the course. To its largest extent, one respondent in engineering had a plan (and green light from the department) to create a new course with field-specific sustainability fully integrated as the main focus of the course, and after piloting, even to be developed further into a MOOC.
Our key observation on this behavioural change of teachers into actually implementing sustainability integration is that the teachers need to find their own way of doing it. As many teachers felt operating in an area beyond their comfort zone and core expertise, they needed to figure out which ways of teaching would fit their purpose and styles best. This connects again to the learning through sharing - as one participant pointed out, learning from peers about different alternative ways to approach sustainability integration will help them find the suitable ones for their specific needs and styles. Whatever type of integration the teacher finds suitable for their respective course, it must be a fit, not “*artificial*” (E8).

3.4 Organizational impact (Level 4)

We identify preliminary signs in the data that the pedagogical course might also support the changes at the organizational level (Kirkpatrick model level 4). The interviewees spoke about discussions they had had regarding founding a new course in the curriculum and about agreeing together with the programme teaching team on how sustainability integration would be furthered in the future. However, in-depth insight into the long-term impact of the training would require further analysis of the organization-level changes. On the other hand, as Cahapay (2021) has pointed out, factors influencing that level are myriad, and discerning whether the long-term impact is due to the training, or a result of external factors, is hardly possible.

4 SUMMARY

In summary, our analysis indicates that the SiT-course seems to be an effective tool to support integration of sustainability into engineering education as a cross-cutting and cross-disciplinary theme. Based on teacher self-evaluation, significant learning has happened at least in some areas of sustainability integration. According to our findings, combining knowledge about sustainability and sustainability education with learning activities focusing on one's own teaching context, and supporting both individual and collective reflection across disciplines have made this course an effective measure to support sustainability integration.

A training course may work as a platform for networking, sharing, and learning with peers, thus providing a way to overcome the time constraints hindering sustainability integration (Karvinen et al. 2017). In addition, the course may result in a more comprehensive and deep approach to sustainability in teaching, help teachers in finding meaningful connections between their subject and sustainability, lower the threshold of individual teachers to start integrating sustainability, and could even work as a means to achieve institution-level changes for sustainability.

While not addressed in our study as such, we believe that a training like the SiT-course could be transferrable to other HEIs of engineering, as well. The course has been showcased at various seminars and discussion events in the European context, especially within the UNITE-network, and it has raised interest, inquiries and appraisal as a concrete measure to advance capabilities for sustainability. Reflecting the unique combination of educational fields at Aalto University (engineering, science, arts, business), the course is designed to support teachers from various fields and thus, making transfer more easy. However, customization to best serve each institutions specific needs is necessary. For continuous learning and development, we encourage sharing of experiences in teacher training for sustainability integration within the HEIs.

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CURRICULUM WORKSHOP AS METHOD OF INTERDISCIPLINARY CURRICULUM DEVELOPMENT: A CASE STUDY OF ARTIFICIAL INTELLIGENCE IN ENGINEERING

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ABSTRACT

The integration of tools and methods of Artificial Intelligence (AI) into the engineering domain has become increasingly important, and with it comes a shift in required competencies. As a result, engineering education should now incorporate AI

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competencies into its courses and curricula. While interdisciplinary education at a subject level has already been explored, the development of interdisciplinary curricula often presents a challenge. This paper investigates the use of the curriculum workshop method for developing interdisciplinary, competence-oriented curricula. Using a case study of a newly developed interdisciplinary Bachelor program for AI in Engineering, the study evaluates the instrument of the curriculum workshop. The communicative methods of the tool and various aspects of its implementation through self-evaluation procedures and surveys of workshop participants are discussed. The results show that the structure and competence orientation of the method facilitate alignment among participants from different disciplinary backgrounds. However, it is also important to consolidate the mutually developed broad ideas for the curriculum design into concrete outcomes, such as a competence profile. Interdisciplinary curriculum development needs to take into account different perspectives and demands towards the curriculum which increases complexity and requires a more structured design process. The findings of the paper highlight the importance of interdisciplinary curriculum design in engineering education and provide practical insights in the application of tools for the creation of competence-oriented curricula in curriculum workshops, thereby contributing to the development of future engineers.

1 INTRODUCTION

The application of Artificial Intelligence (AI) as a tool becomes more and more relevant in the engineering domain. This shift also results in new demands from the market towards the education of future engineers and highlights the importance of interdisciplinary approaches (Gumaelius and Kolmos 2019). From an engineering education standpoint, the advancement of the application of AI in the engineering field requires transforming study programs and the respective curricula to incorporate these new competence requirements while at the same time addressing the specific context of the engineering domain (How and Hung 2019; Schleiss et al. 2022). Thus, interdisciplinary engineering education approaches and close collaboration between different disciplines are essential.

In the context of this paper, we refer to a curriculum as the decision of what students should learn and the collection of subjects offered to address this particular learning goal. Hence, curricula are more than a compilation of stand-alone subjects, but design an overarching framework for the development of an academically trained personality. Here, interdisciplinary curricula are often expected to address knowledge and skills that address students' real-world problem-solving competencies (van den Beemt et al. 2020).

At the same time, designing interdisciplinary curricula is a complex task and comes with several challenges. One challenge is determining the sequence in which the students learn content, either going deeper in a single discipline or understanding the breadth of the field first (Bächthold 2013). Moreover, designing interdisciplinary curricula requires finding an agreement between different discipline cultures, experiences, and interests (Millar 2020). It requires finding a common ground and mutual understanding. Overall, interdisciplinary curriculum development is a difficult task but can be key for bringing new perspectives and competencies to engineering education (van den Beemt et al. 2020).

In this paper, we focus on the question on how well the curriculum workshop method is suited for the development of interdisciplinary curricula at the intersection of AI and engineering with regard to interdisciplinarity, cooperation, participation, and composition. Moreover, we investigate key considerations in implementing the curriculum workshop method in an interdisciplinary setting. We analyze the use of curriculum workshops in the development of a novel bachelor program at the intersection of AI and engineering as a case study. Overall, our study contributes to an improved understanding of the process and considerations in interdisciplinary curricula development and the use of the curricula workshop method in an interdisciplinary setting.

2 RELATED WORK

2.1 Interdisciplinary Engineering Education

Interdisciplinary engineering education builds on the idea to bridge the different epistemologies of disciplines and to integrate content and concepts from different disciplines into one teaching approach (van den Beemt et al. 2020; Lindvig and Ulriksen 2019; Spelt et al. 2009). It is often built with the vision to develop competencies for complex real-world situations, such as collaboration or communication (van den Beemt et al. 2020; Lindvig and Ulriksen 2019; Lattuca et al. 2017) and in return, increase the employability of future engineers (Gumaelius and Kolmos 2019). Moreover, interdisciplinary teaching should improve disciplinary programs and the students' motivations (van den Beemt et al. 2020; Lindvig and Ulriksen 2019).

Research on interdisciplinary curriculum design indicates that interdisciplinary knowledge is less clearly classified as compared to discipline-based knowledge (Millar 2015), which Millar (2016) and Muller (2016) link to a limited depth of knowledge that students encounter in interdisciplinary curricula. This indicates that interdisciplinary curriculum development needs a careful balance between width and breadth (Bächtold 2013; Blizzard et al. 2012).

2.2 Curriculum Development Approaches

A structured, competence-oriented, and student-centered development of study programs can be approached from multiple perspectives. Although there are different approaches to curricula development (Schaper et al. 2012; Kern 2016; O'Neil 2015, Gotzen et al. 2018), they share similar characteristics. The design of the curriculum usually starts with an analysis of the context in which the curriculum is embedded. Next, learning objectives and outcomes are defined and appropriate teaching methods are selected. Then, the curriculum is implemented and evaluated to ensure, that the set goals are achieved. Curriculum development, therefore represents an iterative, ongoing and reflexive process aimed at continuous improvement and adaptation of the curriculum.

Schaper et al. (2012) presented basic principles of competence-oriented curriculum development, introducing various possibilities of programme and curriculum development, which refer to both, a theoretically based approach from the academic domain and a practice-guided approach. According to the authors, there are three different ways to curriculum development. First, the use of already existing mission statements and training standards or competence profiles. Second, surveying graduates of comparable study programmes and subject-specific employers and third, participatory methods for the development of novel and non-comparable degree programmes.

Here, the case study of AI in engineering targets a novel curricula development which has no existing references of competence profiles or existing programmes. This interdisciplinary setting at the intersection of AI and engineering involves participants from multiple domains, with different experiences and broad demands on the curricula. Thus, a participatory approach is chosen to foster the discussion and alignment between all stakeholders.

2.3 Artificial Intelligence Education in Engineering

AI is becoming increasingly relevant in engineering education (Gumaelius and Kolmos 2019). Schleiss et al. (2022) proposed an interdisciplinary competence profile for AI in Engineering, highlighting the need for interdisciplinary access that includes interdisciplinary communication skills and methodological skills along with solid professional competencies in AI and the domain.

AI education itself is often discussed in an interdisciplinary setting due to its roots in the fields of philosophy, neuroscience, psychology, cognitive science, and math (Mishra and Siy 2020). Janssen et al. (2020) reported, for example, on experiences of an interdisciplinary AI master program. Their curriculum is built around six core characteristics: (1) courses are taught by multidisciplinary and interdisciplinary staff, (2) engineering techniques and theory are used hand-in-hand, connecting implementation to theoretical concepts, (3) students are given choices in assessment and presentations to allow for individual interests, (4) highlighting relevance to practice and industry, (5) highlight multidisciplinary origins of machine learning, and (6) balancing skill levels. Similarly, Ng et al. (2022) argued that AI literacy should not be seen as specialized field under engineering but should be seen as a competence for students from all disciplines and levels. Moreover, How and Hung (2019) suggested that AI education for STEAM education differs from Computer Science AI education.

Working with AI can also have ethical, legal, and social implications. Thus, ethics education needs to be integrated into AI education to foster the understanding and discussion of ethical, social, and legal implications of the application of AI (Borenstein and Howard 2021; Furey and Martin 2019). This can include, for example, developing an understanding of bias, fairness, explainability, privacy, trust, and transparency. Overall, this highlights the complex needs and requirements to integrate multiple perspectives into an interdisciplinary curriculum for AI in Engineering.

3 CASE STUDY: INTERDISCIPLINARY CURRICULUM DEVELOPMENT FOR A BACHELOR PROGRAM AI ENGINEERING

3.1 Methodology

The study employs a design-based research approach (Anderson and Shattuck 2012). The curriculum workshop, which refers to a series of workshop sessions with all involved stakeholders from the participating disciplines, was developed based on existing approaches for the development of study programs from literature (Section 2.3). This theoretical artifact was tested in practice with a case study of a curriculum workshop series for an interdisciplinary bachelor program at the intersection of AI and engineering. The case study is analyzed through self-evaluation procedures of the facilitators (authors) and quantitative ex-post surveys with the participants at the end of the workshop series.

3.2 Methodological Approach of the Curriculum Workshop Series

The curriculum workshop addressed in this paper was conducted in three phases, which were run through several workshop sessions (Fig. 1). The first phase covered the problem identification and a general needs analysis. The aim was to create a common starting point for the development of the curriculum. The second phase aimed to develop a coherent competence profile of the overall program. The competence profile built the foundation of competencies the graduate will have upon completion of the program. The third phase aimed at developing a module matrix and the lecture design.

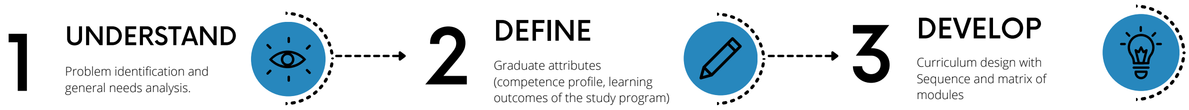

Fig. 1: Three phases of the curriculum workshop method

3.3 Implementation

The bachelor program of the investigated case study is a collaboration between five higher education institutions. Therefore, the development process was conducted in online workshops. Overall, ten curriculum workshops were held in the process of development between February 2022 and July 2022. The participants were part of the development process and were delegated by the participating universities. The composition of participants changed in part.

Each workshop session was conducted by two facilitators and supported by an impulse presentation. After an introduction to the content and a short update of for participants, the workshop focused on co-creation in smaller sub-groups on the respective topics. Participants worked on a visual collaboration platform, allowing synchronous work and compiling of results. At the end of each session, the results were brought together into the plenum. Following each workshop session, the results produced through group or individual work were categorized, sorted, and further edited in such a way that, if possible, a new artifact of the development process emerged.

3.4 Interdisciplinarity in the Development

Interdisciplinarity in this context describes both a collaboration of the disciplines between engineering sciences and AI, as well as between the different engineering disciplines. To practice participative co-creation, it was aimed to ensure that at least one representative from each institution and each subject area could participate in each session. At the same time, participants could freely choose to participate based on their availability, leading to an unbalanced number between institutions or disciplines in some workshop sessions. In the development of the competence profile and the module matrix, a concentration of expertise was achieved through small group work according to subject affiliation, which was then brought together and discussed in the large group. The mixing and discussion led to an exchange between the disciplines.

3.5 Evaluation

The effectiveness of the approach was assessed using both self-evaluation procedures with the facilitators and quantitative ex-post surveys among the participants after completion of the workshop series.

The ex-post evaluation focused on key areas such as the implementation and methodology of the curriculum workshops, as well as the level of specificity and successful implementation of interdisciplinary curriculum development within the workshops. For the survey, all those who had participated in at least one session were contacted and reminded twice; this applied to 30 people. Of these, 14 took part in the survey. The data was analyzed using IBM SPSS Statistics. The closed-ended items of the survey were reported indicating the extreme values.

4 RESULTS

4.1 Self-Evaluation of Facilitators

The experience of the workshop facilitators indicates that it is important to keep the session format flexible, to plan in sufficient time buffers to integrate many different perspectives, and to give everyone the space to contribute their perspectives. In contrast to one thematic focus, it is important to run through content goals several times in order to absorb interdisciplinarity. In addition, intensive preparation and follow-up as well as the formulation of clear work assignments are essential to involve all participants in the process. This was particularly important since the participants changed between the individual curriculum workshops. The online format proved to be very profitable and made it possible to bring together the different interest groups in a digital space despite the physical distance.

4.2 Ex-post Evaluation of Participants

These experiences can also be confirmed by the ex-post evaluation. The majority of the fourteen participants was academic staff, and three of whom stated that they were professors. Half said they belonged to the computer science domain, and the other half assigned themselves to the engineering domain. The evaluation of the curriculum workshop was carried out concerning the implementation, the method as well as the topic of interdisciplinarity.

Implementation of the curriculum workshops The implementation of the curriculum workshop sessions was surveyed through eight individual items using a 5-point Likert scale (1 "do not agree at all" to 5 "agree completely"). Overall, the implementation was evaluated very positively by the majority of the 14 respondents (agreement by 10 or more of the respondents on good preparation, use of tools was helpful, appropriate duration).

Method of the curriculum workshops Respondents were also asked to rate eight individual items regarding the methods of the curriculum workshop. The majority of respondents (12 out of 13) agreed that the curriculum workshop sessions were helpful in exchanging ideas and perceptions and that it was a participatory method (scores of 4 and 5 on a scale of 1 "do not agree at all" to 5 "agree completely"). Only six of the 13 respondents, however, agreed with the statement "The curriculum workshop method was helpful in working out formulations." (4 and 5 on the scale).

Interdisciplinary Cooperation and Participation Almost three-quarters of the respondents (9 out of 13) agree with the statement that the curriculum workshop is a suitable tool for taking interdisciplinary perspectives into account. The majority of respondents agreed with the statements "I was able to work productively with representatives of other subjects and/or subject cultures" (11 out of 13 respondents), "I consider the interdisciplinary cooperation to be profitable overall" (12 out of 13 respondents) and "Difficulties in understanding between subjects and/or subject cultures were addressed by the moderation" (11 out of 13 respondents) (in each case values 4 and 5 on a scale from 1 "do not agree at all" to 5 "agree completely"). Participants partly reported problems with interdisciplinary cooperation in the workshops, but the frequency of the problems was estimated by most only as occasional (see Fig. 2).

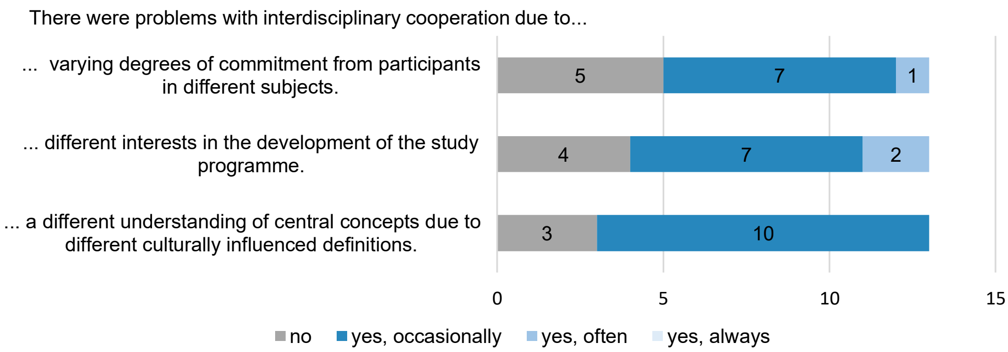

Fig. 2: Problems with interdisciplinary cooperation within curriculum workshop sessions (absolute frequencies; n=13)

Overall Recommendation Overall, eleven of the 13 respondents find that the use of the curriculum workshop method would be recommendable when creating a new interdisciplinary degree program (8 of 13 "Yes, definitely"; 3 of 13 "Yes, probably"). Only two of the 13 respondents find the method is rather not recommendable.

5 DISCUSSION

Curriculum workshops in an interdisciplinary setting

Overall, the curriculum workshop method can be considered a suitable format for interdisciplinary curriculum development. It enables a creativity-promoting exchange format, the collection and specification of ideas with the participation of the disciplines involved and does not require guidelines from existing study programmes. The evaluation results indicate that considering individual interests and planning sufficient time for it is a key consideration in interdisciplinary cooperation in the workshop sessions. Moreover, it is important to tackle certain tasks and questions several times to allow participants to take different perspectives. At the same time, participants felt their interests were sufficiently taken into account and they could participate productively throughout the workshop series.

The experiences of our case study indicate that the curriculum workshop method is suitable for creative brainstorming and creating a consensus but not so much for the concrete formulation of outcomes, e.g. in descriptions of a profile or module. In our experience, connecting the findings and creating condensed outcome reports, and discussing them within the next session has been a way to move forward and not get stuck in detail. Concerning working with different cultures, backgrounds and experiences, it has shown important to create a mutual understanding of the topics, e.g. through giving input or context.

Limitations of the study The presented study has three limitations. First, the presented evaluation and finding stems from the implementation of one curriculum workshop series. Therefore, conducting it in another setting would give more insights into the generalizability of the findings. Second, the study focused only on the process of development, not the quality of the outcome. Third, throughout the development, the participants that took part in the workshops were not fixed. Thus, we asked participants to evaluate the whole approach as a workshop series, not single sessions.

Implications for the community The study can give new impulses for instructors, curriculum developers, and faculties on how to approach interdisciplinarity in curriculum development, especially with a focus on bringing AI into engineering education. This addresses the question of what knowledge and skills are relevant for future engineers to be prepared for their future jobs (Gumaelius and Kolmos 2019; Millar 2015). Moreover, findings and considerations from this study can be transferred into interdisciplinary curriculum developments at other future trends, such as the intersection of sustainability and engineering.

6 CONCLUSION AND FUTURE WORK

In this paper, we focused on investigating how well the curriculum workshop method is suited for the development of interdisciplinary curricula at the intersection of AI and engineering with regard to interdisciplinarity, cooperation, participation, and composition. Moreover, we looked into key considerations in implementing the curriculum workshop method in an interdisciplinary setting. In analyzing the use of curriculum workshop sessions in the development of a novel bachelor program at the intersection of AI and engineering, we found that the method is a suitable format for an interdisciplinary curriculum development. Its strength lay in a collaborative and structured working environment that allows taking into account multiple disciplinary perspectives. Moreover, it can be adapted to the needs of each group. At the same time, the evaluation indicates that the method is suitable to create new insights but not so much for the concrete formulation of outcomes.

Further research will evaluate the outcome of the curriculum development through competency mapping. Moreover, further studies could investigate how input and feedback from different stakeholders such as industry partners and practitioners can be included in curriculum development approaches to ensure relevance and applicability.

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HOW TO DEVELOP TEACHERS' WELL-BEING?

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ABSTRACT

The well-being of teachers is one key to students' and education's success. As an innovative solution, we hold a training program for educators using design thinking based on the "Designing Your Life" program that can be familiar with engineering educators' mindsets. We adopted it for the Hungarian circumstances and made one pilot program and one real program with the self-applying teachers at the Budapest University of Technology and Economics. We surveyed teachers' well-being with the PERMA Profiler at the beginning of the program and one month after the program in both samples and had in total of 41 answers (n=23). Based on the results, such programs can help to enhance teachers' well-being, and in this way, universities can offer a better emotional climate and prevent teachers' and students' burnout.

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1 INTRODUCTION

Nowadays, higher education is even more of a service and has to be competitive. Based on findings of organizational psychology, companies are more performative with happier and satisfied employees. This paper shows an exciting staff development program designed for engineering educators.

1.1 Well-being of Educators

Well-being is a popular concept nowadays. The well-being of university teachers is a crucial point of the efficiency of education itself, the educators' academic success, relationships between colleagues, and teacher-student interactions (Rahm, Heise, 2019; Ballantyne, Retell, 2020; Smetackova et al., 2019).

There are many positive psychological approaches to well-being, but the PERMA framework is widely accepted among psychologists and scientists, and based on empirical evidence, it seems to be the most appropriate to operationalize it in a workplace context (Donaldson et al., 2022; Linton et al., 2016).The original model was developed by Seligman (2002), who said that to reach the state of well-being, we have to fulfill 5 different components related to a flourishing life (Seligman, 2011). The five pillars need to come together:

- Positive emotions: this hedonic component of well-being includes positive emotions such as hope, fun, satisfaction, happiness, and commitment (Seligman, 2011).
- Engagement: focuses on activities of daily living and having a high level of interest in these activities (Seligman, 2011) . This can feel in workplace settings and means that our goals are in line with our abilities, and we feel the intrinsic motivation as a gate to flow experience (Nakamura, Csikszenmihalyi, 2014).
- Relationships: the feeling of being cared for by others and developing relationships based on trust and authenticity, being valued by loved ones, integrating with society, and being satisfied with their social network (Khaw, Kern, 2014).
- Meaning: makes the life worth living. The individual directs their life towards a purpose they think is directed towards a greater purpose than themselves to continue their life (Steger, 2018).
- Accomplishment: it can take many forms, from workplace to personal development. This makes progress and increases success in different areas of life in line with personal goals (Seligman, 2011).
- Other factors can also be considered by well-being: physical health, presence of negative emotions, feelings of happiness, and loneliness. With these factors we got a holistic model (Butler, Kern, 2016).

1.2 Designing Your Life Program

Our Designing your life Program (DYLF) is based on Burnett and Evans's "Designing your life" and "Designing your work life" methodologies (Burnett, Evans, 2016; 2018; 2020). Regarding the authors' idea, a well-designed life is the key to a well-lived life and well-being. The idea came up first as a class at Stanford University designed for design students. In this approach, they used techniques that fit designers' mindsets, which means it is suitable for people who like to solve problems. Design thinking-based life coaching programs have gained popularity worldwide, with organizations combining design principles and coaching techniques to help individuals navigate personal and professional challenges. Several design thinking-focused life coaching programs in Europe have emerged, such as the "Design Your Life" workshops offered by renowned design consultancy firms like IDEO. These programs encourage participants to apply design thinking methodologies to their personal lives, fostering creativity and problem-solving skills.

Within BME, courses with a similar theme are available to students, but they focus more on starting a career. Our DYLF program helps those not at the beginning of their career and have work experience.

Now, the program built 5 phases, and we completed the basic program with some extra elements, like time management, work-life balance, stress management, and self-branding. The phases were:

- State analysis: it reviews the current life situations and the most critical areas of life.
- Making a personal compass: describe the most important personal values of the work-life and life.
- Sketching plans: design 5-year-long plans with different conditions. It helps to reframe the problems and determine the most appropriate questions.
- Prototype: defining some major short-term projects from the plans is very important to design prototypes. With prototypes (for example, interviewing somebody with experience in the field of the short-term project), participants gain experience, and they can make better decisions with less risk in their life plans.
- Real projects: after the prototyping phase, they can determine project plans (Burnett, Evans, 2016; 2018; 2020).

Some concrete tasks are listed in Table 1.

1.3 Research Questions

Based on our 15 years of experience and the literature review, by preparing a more extensive staff development program, we link specific tasks of the DYLF program to the elements of PERMA, as shown in Table 1. Furthermore, finally, the question emerged whether the Designing Your Life Program is adequate and appropriate enough to enhance engineering educators' well-being. This paper gives a brief insight into the pilot program.

Table 1. How DYLF program elements (Burnett, Evans, 2016; 2018; 2020) promote PERMA factors (Seligman, 2011, Butler, Kern, 2016)

PERMA factors	DYLF task	Expected outcomes
Positive emotions	good times diary	more openness and self-acceptance
Engagement	work and life attitude	change of focus, higher level of motivation, finding intrinsic motivation
Relationships	index of supporters	ask for feedback, new relationships, and better communication skills
Meaning	Odyssey plan	finding deeper and more complex meaning
Accomplishment	prototype testing plan	smart goals, better planning, measurable results, tools for self-development

Health	gas tank	importance of me-time, higher level of self-awareness, better physical health
Negative emotions	concrete action plan	focus on one's strengths, self-compassion
Happiness	anti-job description	diversity, new inspirations
Loneliness	index of supporters	networking, courage to show oneself to others

2 METHODOLOGY

2.1 Adaptation of the Program

This research aims to identify how practical the Hungarian application of "Designing Your Life" was among teachers at the Budapest University of Technology and Economics.

The program went with 2 co-trainers who developed a 5+1 session workshop based on the engineering educators' needs. We applied the original methodology to our course, but generally, we thought that the idea of design thinking fits engineering and economics educators' mindsets.
The main changes to the original program were:

- one short motivational session before the program starts to explore the unique needs of teachers;

- offline sessions in groups of 8-12;

- each topic was the focus of different sessions;

- one personal or online closing coaching session by one-by-one.

2.2 Measurement

We used the PERMA Profiler to explore the group members' well-being and changes (Butler, Kern, 2016). This tool separately measures the five pillars of well-being (positive emotions, engagement, relationships, meaning, and accomplishment) and four subdimensions: happiness, loneliness, negative affect, and health. This extended scale consists of 23 items.

We asked the participants to complete the test via an online form at the beginning of the program and several months after the closing session. In the follow-up questionnaire, we again used the PERMA Profiler and asked for their subjective feedback about the program's effectiveness and personal development. We make the same process for both groups. In Figure 1., we show the research timeline, and in Table 2., we offer the sample sizes.

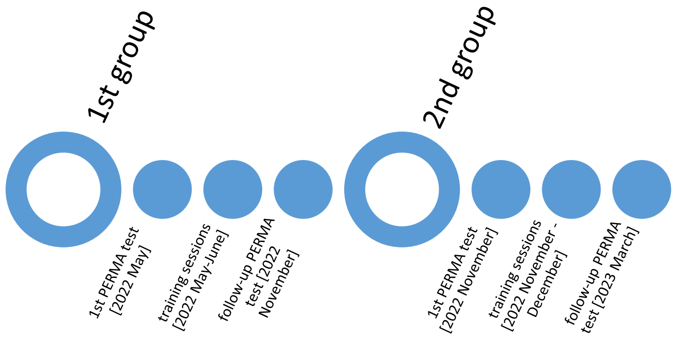

Figure 1. Timeline of the research project

Table 2. Sample sizes

	n of participants	n of 1st measure	n of 2nd measure
Sample 1 (1st group)	11	11	9
Sample 2 (2nd group)	12	12	11

Each participant was a Ph.D. student or post-doc staff member of the Budapest University of Technology and Economics, aged 22-30, both men and women. They came from different university faculties, such as mechanical engineering, chemistry, architecture, informatics, electrical engineering, and economic sciences.

During the motivational interview, the participants named their problems, such as burnout, work-life misbalance, poor carrier opportunities, and emotional exhaustion, that they want to work with this program. They did not participate in other similar programs, either at the university (this workplace did not offer any) or on their own.

3 RESULTS

3.1 PERMA Scores

Based on Butler and Kern's scoring key, we used the IBM SPSS Statistics 25 software to analyze our data. In Table 3. we show the descriptive data of the first measurement and the ranges of the scores (Butler, Kern, 2016).

Table 3. Descriptives of the 1st PERMA measurement (n=23)

	Mean	Std. deviation	Min. -max.	Score ranges
Positive emotions	18,9565	4,21554	7-26	3-30
Engagement	19,0435	4,85684	10-26	3-30
Relationships	22,1304	3,81748	14-28	3-30
Meaning	21,9565	4,49725	9-28	3-30
Accomplishment	22,9130	3,20388	13-27	3-30
Health	20,2174	5,59997	9-29	3-30
Negative emotions	17,3913	3,84636	8-25	3-30
Happiness	6,8696	1,45553	3-9	1-10
Loneliness	4,4783	2,19233	2-9	1-10

The scores are in the low-moderate range, so we can see that the teachers' well-being is not high at the beginning. Their emotional life is weak, poor in positive and negative emotions, they are moderately happy and do not feel too much engagement, and they are unsatisfied with their health. More robust pillars of well-being are meaning and accomplishment, meaning they find their work challenging (maybe too much) and can see the purpose in a long time. Their strongest pillar of well-being is relationships, but we do not know whether they think about relationships with students, colleagues, or other connections outside of the university.

In Figure 2. we show the changes between the two measurements. After the Designing Your Life workshop sessions, we see a positive shift in 8 scales between the 9 subscales. In 7 scales, this is a 0,5-2 point high shift, which means 1-7% change, and we can see the same decrease range in case of negative emotions. The only scale where there was no positive change is loneliness.

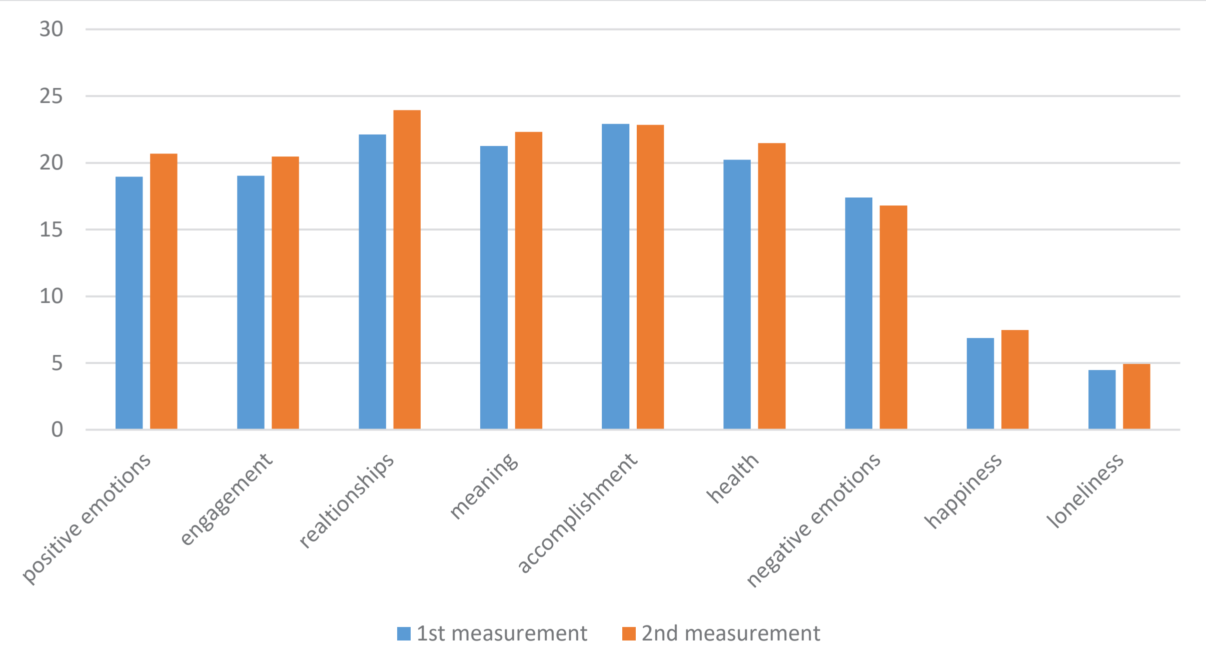

Figure 2. Timeline of the research project

We used Friedman's two-way variance analysis to analyze the difference between the 2 measurements. This said that the distribution of the PERMA pillars changed. We see higher maximum scores on scales of positive emotions, engagement, relationships, health, and happiness and lower maximums on scales of negative emotions and loneliness.

We could not find any significant difference by comparing the means of the scales with the nonparametric Mann-Whitney test. We see the positive tendency of whether the sub-sample sizes are too big to show statistical significance. We can see more than 1 point shift in the scales of relationships (1,8), positive emotions (1,7), engagement (1,4), and health (1,3).

If we analyze the two training groups separately with the Mann-Whitney test, we can find one significant difference in the case of the 2nd group. Generally, by the 2nd group, each scale has higher points at the beginning and the follow-up measure. On the scale of the relations, the statistics show a difference in the distribution on the .006 significance level, which means a shift of almost 4 points (from 22.4 to 26.2).

3.2 Qualitative results

Whether we accept the closing one-by-one coaching session as qualitative feedback about the program’s effectiveness, the participants found the training useful andy they were plased to their decision to participate on the course. We didn’t record these sessions because they were really personal but asked the participants whether we could use their experiences and answers anonymously.

In the subjective part of the follow-up questionnaire, a few months after the sessions, participants referred to our expected outcomes shown in Table 1. in their own words, as shown in Figure 3.

Figure 3. Subjective experiences from the follow-up questionnaire (higher font size means that more particapnts had the same impression)

4 SUMMARY

Based on the statistical analysis, the results of the PERMA profiler are perspective. Even on this tiny dataset, we can see the statistically significant positive effect at the second measurement. As relationships are essential for well-being (Seligman, 2002; Seligman, 2011; Khaw, Kern, 2014) and the program has its’ effect on the relationship scale, we can say that the Designing your life program seems to be appropriate for engineering university teachers.

During the workshops, the participants got feedback and social support from their peers. This new network can prevent burnout and gives them positive emotional experiences. Participants became braver to show themselves and ask for feedback while practicing the learned skills and using the program’s tools daily. Another message of the workshop for teachers is that the university cares about them. So the new relationships and belonging to the university brand have a joint positive effect.

On the other hand, at the end of the course, the participants had concrete plans for the following months. They got tools to use in their daily life and planning to be more accurate and flexible simultaneously. These tools and plans can lead them through the difficulties of academic carrier building so that they can set more appropriate achievements. Planning their own life seems to be a difficult task even for engineers too. They learned that it is very important to spend time with themselves, observe and reflect on their inner world.

Thirdly, the design of the workshops is familiar to engineers' thinking, and with these small changes, we adapted it to our university's circumstances. This personalizing helps to hold more appropriate training based on participants' needs. These changes must be based on the shared knowledge and values of the staff. Moreover, it strengthens the common positive feelings of a collective.

To generalize our conclusion, we must repeat the measurement on a more extensive dataset, and in that case, we should measure and control more starting and outcome variables. However, each program dedicated to increasing well-being seems useful in universities during these turbulently changing times.

In the case of higher education or especially engineering education, we focus on learning materials, teaching methodology, and students' characteristics, but we have no eyes on the staff itself. This study aimed to show that only one, appropriately designed program can enhance educators' well-being, leading to more satisfied employees and a better level of service.

Even with the limitation of the ecological validity of this study, the attitude of such a process is refreshing in higher education. Engineering educators seem to be more familiar with design thinking linked with some positive psychological spirit than a specific soft skill development training program.

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WHY DO STUDENTS DISLIKE PEER FEEDBACK?

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Conference Key Areas: *Engineering Skills and Competences, Innovative Teaching and Learning Methods*
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ABSTRACT

Engineers are required to communicate in a range of formats, including written reports, but this skill does not come naturally to undergraduates. Typical approaches to teaching writing skills require small class sizes, expert staff, and multiple cycles of feedback. These approaches, while successful, are difficult to scale and do not always result in students being able to transfer their writing skills to other units/topics.

The School of Civil, Aerospace, and Mechanical Engineering at the University of Bristol teaches writing skills mainly within a single 20-credit first-year unit, delivered to 550-650 students per year. Students are required to complete a number of at-home labs and write up various sections of a lab report for a series of four formative assessments. A peer review process follows each formative task to encourage engagement with the assessment criteria, encourage reflection and self-regulation, and provide prompt feedback on work.

The benefits of peer review and feedback are well known and are carefully explained to students. However, each year, a relatively small but vocal number of students are

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reluctant to engage with it and express a strong preference for staff feedback. This project evaluated student perceptions and experiences of the peer review process using a survey and focus groups. Results suggest that although students recognise many benefits of peer reviews, they lack confidence in their ability to provide it, leading to apparent reluctance to engage. This highlights the importance of providing support and training as part of the process.

1 INTRODUCTION

1.1 Teaching writing skills

The ability to communicate is a core competence for professional engineers (EngineeringCouncil 2020), yet students often begin engineering degrees with low ability and interest in written communication (T. Moore and Morton 2017). Various interventions have been attempted to improve writing skills. Teaching writing within specific units (sometimes combined with further 'soft' skills') helps students to focus on developing their skills, but can create silos whereby students are unable to effectively use these skills in other areas (Goldsmith and Willey 2018). Embedding writing within multiple units can overcome this siloing issue, but requires trained staff and a consistent approach, and increases the marking and feedback workload (Wingate, Andon, and Cogo 2011). With larger classes, these problems of providing feedback on multiple practise tasks in a timely manner become even more challenging.

Peer review is one possible solution which moves the feedback load from staff to students, not only helping to manage workload, but also engaging students with assessment criteria and encouraging development of self-regulated behaviours (C. Moore and Teather 2013).

1.2 University of Bristol context

Engineering undergraduates at the University of Bristol across Civil, Mechanical, Aerospace, Engineering Design, and Mechanical and Electrical engineering programmes are taught 100-credits of common units in their first year of studies. Engineering by Investigation is one of these common units – a 20-credit unit with a focus on developing laboratory skills, including written communication skills. A cohort of 550-650 students are taught in active group-based sessions and are required to complete four formative partial lab reports throughout the year. The final assessment is a summative lab report, following the same guidelines and criteria as were used in the formative assessments.

Each formative report submission is followed immediately by a peer review session. The peer review sessions take place in groups of four students, with each student in the group allocated a single review to complete. Students are encouraged to work as a group to review each report, so each student contributes to four reviews. To complete a review, students were required to answer a mix of yes/no and open-ended questions about the report, which were closely mapped onto the summative assessment criteria. While the process implemented was pedagogically sound, staff perceived a continual stream of requests for staff feedback either in addition to, or in place of, peer reviews.

1.3 Project aims

This project forms part of our continual evaluation of teaching practice within the unit and had specific aims of evaluating student perceptions and experiences of the peer review process used during 2021/22 to inform our practice going forwards.

2 METHODOLOGY

This project was given ethics approval by the Faculty of Engineering Research Ethics Committee at the University of Bristol (ref. 10229) prior to commencing data collection. A combination of a survey and focus groups were conducted to collect breadth and depth of information about student perceptions and experiences of the peer review process being used.

2.1 Survey design and implementation

Students were invited to complete a survey during an in-person session held mid-way through the unit, with the aim of maximising the response rate. Students had already completed peer reviews for one formative assessment and were about to complete peer reviews for the second formative assessment. The survey was designed to collect student perceptions of peer reviews and their experience so far of the process used in this unit. The survey was created in MS Forms and a 'tinyurl' link to the survey was shown on screen. Students who accessed the link were able to read the participant information sheet and choose whether to participate or not. The main part of the survey consisted of three open-ended questions and nine five-point Likert-scale questions (Table 1). Attendance at the synchronous sessions was approximately 50% of the cohort, and the majority of students in the room chose to consent and complete the survey, giving 314 responses.

Table 1. Survey questions. The Likert-style questions L1-L9 were preceded by the question: How much do you agree with the following statements?

Q	Question text	Response options
O1	What were your expectations of the peer review process before you had completed any of the peer reviews?	Open-ended free-text response
O2	How would you describe your experience of giving peer reviews?	
O3	How would you describe your experience of receiving peer reviews?	
L1	Student feedback is more likely to be phrased in a way I can understand than staff feedback.	Five-point Likert-scale: strongly disagree, partly disagree, neutral, partly agree, strongly agree
L2	Giving feedback to my peers helps me to understand how my work will be assessed.	
L3	I learn more by receiving a peer review than giving a peer review.	
L4	Giving feedback to peers is a skill that I will use in the future.	
L5	I have made changes to my work as a result of the peer review process.	
L6	I learn more from giving a peer review than I would from receiving staff feedback.	
L7	I think that staff feedback would be less detailed than student feedback.	
L8	I think that student feedback is more likely to be correct than staff feedback.	
L9	Overall, there are some benefits in receiving feedback from students instead of staff.	

2.2 Focus group design and implementation

Focus groups were conducted to further investigate some of the themes raised by responses to the survey. Survey participants had been asked whether they were willing to be contacted to take part in a voluntary follow-up focus group. A random selection of participants were invited, with a target of having six participants in each of eight one-hour groups. Groups were semi-structured, with the lead investigator on the project posing initial questions to start discussions, but also allowing participants to take the conversation in whatever direction they wanted (Morgan 1998).

Due to timetabling constraints, focus groups were held at the end of the unit and after assessments in other units had been completed. Due to this timing, and a low response to invitiations, only three groups were run with three, three, and one participants.

3 RESULTS

314 completed surveys were received and analysed. Responses to Likert-scale survey questions are shown in Fig. 1. Overall, students recognised a benefit in receiving peer rather than staff feedback (L9), and appreciated that peer feedback had helped them to improve their work and understand the assessment criteria (L2, L5). Responses were split over whether the reviewer or reviewee benefitted most from peer review (L3) and whether staff or student feedback was more accessible (L1).

Despite these positive responses, there were also a number of negative perceptions – students reported perceptions that staff feedback would be more detailed, and more correct than peer reviews, and would therefore help them learn more (L6, L7, L8).

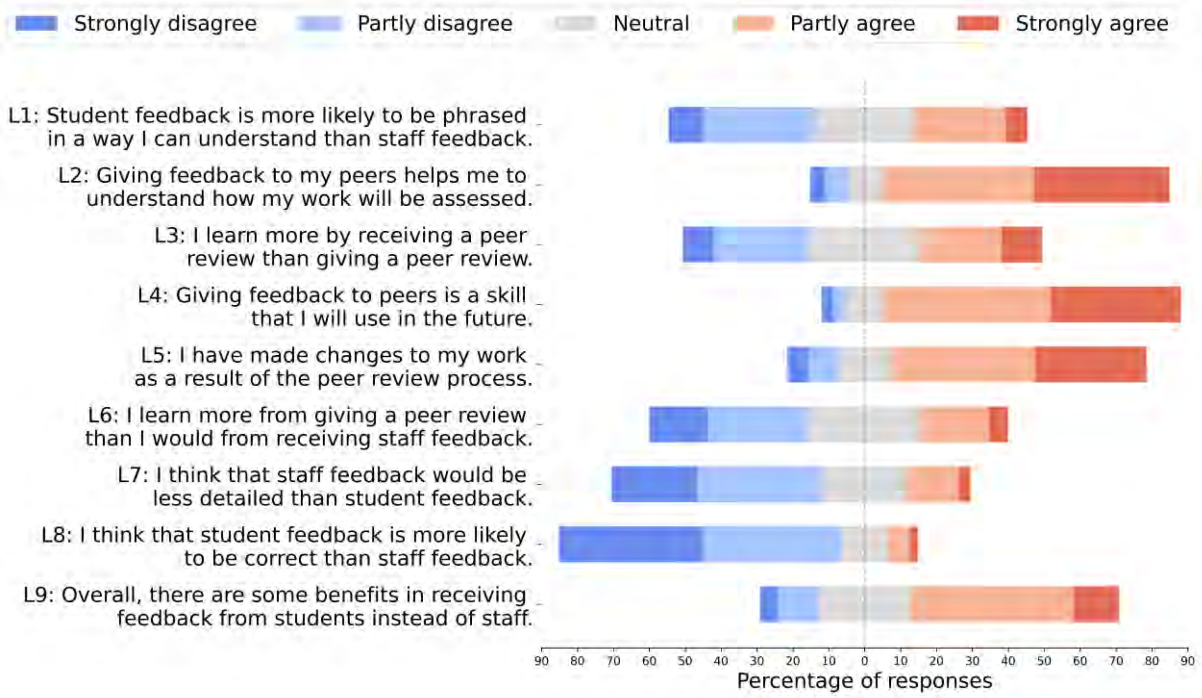

Fig. 1. Summary of responses to Likert-scale survey questions

Open-ended survey questions were analysed using reflexive thematic analysis, with the lead investigator familiarising themselves with the data and attempting to group similar comments together into themes (Braun and Clarke 2020). This process was repeated multiple times until all responses fitted satisfactorily into a theme. Three overarching themes were chosen, with several sub-categories within each theme, as shown in Fig. 2.

The small size of the focus groups meant that they did not function as intended, but some expansion on the themes from the survey data was attempted. The main theme raised by focus group participants was the 'Lack of confidence' previously identified in the survey results, especially the 'Student is not an expert (but teacher is)' sub-category.

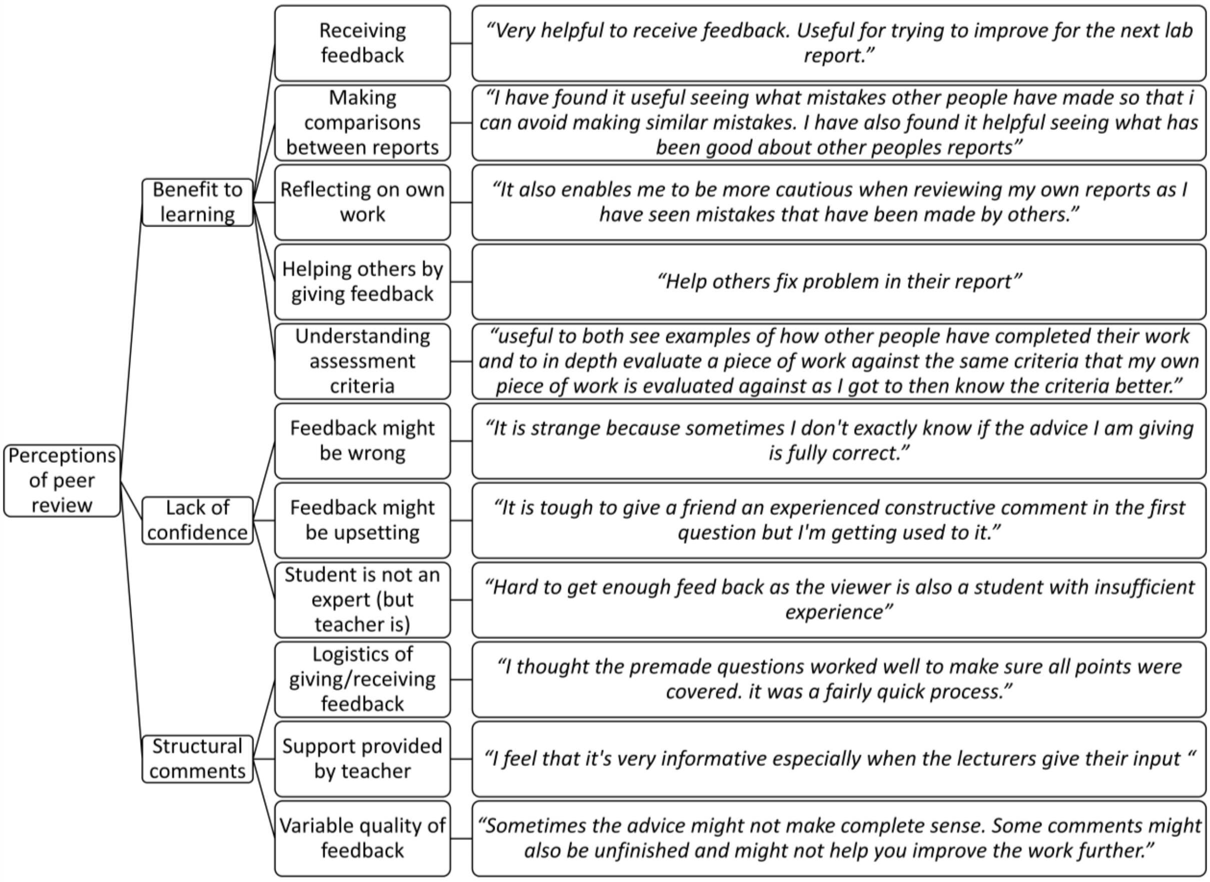

Fig. 2. Themes identified in open-ended survey questions and focus group discussions, together with sample comments for each category.

4 DISCUSSION

The positive perceptions reported by participants suggest that the process is successfully supporting them to become self-regulated learners who are able to internalise assessment expectations and modify their work accordingly (Zimmerman 2002). Students were also positive about the structure of the peer review process, suggesting that the detailed review questions were helpful both for providing feedback and interpreting feedback to make improvements. This is consistent with literature showing that providing question prompts increases student engagement with peer feedback (Jurkowski 2018).

The negative views of peer reviews perceived by staff appeared to be driven by a lack of confidence among students – which is entirely probable when considering a first-year cohort learning new skills (writing skills). Research has previously confirmed that active learning strategies, of which peer review would be one example, can cause anxiety in students for a number of reasons, including not knowing whether their answer is correct (England, Brigati, and Schussler 2017). Active learning strategies have also been shown to divide student opinion, which explains the opposing responses seen for all questions in the survey (Patrick 2020).

This project has shown that students found peer review helpful for their understanding of assessment criteria (both L2 and 'Understanding assessment criteria' sub-theme), which is a key skill in transitioning to and succeeding in university studies. Implementing peer review more widely throughout a programme could have significant positive effects on students internalising assessment criteria, while also mitigating some of the negative experiences caused by a lack of familiarity with the process and confidence in their own abilities.

Students also appreciated the value of peer review to their future careers (L4), and reported the usefulness of the reflective and critical thinking skills that were being developed ('Benefit to learning' theme). These skills are essential attributes for graduate engineers, and are strongly supported by engagement with the peer review process (Nicol, Thomson, and Breslin 2014; Hirudayaraj et al. 2021).

4.1 Limitations of the study

There were several limitations of this study. The only students invited to participate were those who attended the second in-person peer review session, so students who had already disengaged from the process (through non-attendance) were not able to take part in the study. Voluntary studies are also affected by participation bias, so the results will not be representative of all students in the cohort. This is partly mitigated by the high number of responses to the survey.

The extremely low uptake of invitations to focus groups, and low conversion of accepted invitation to actual attendance meant that focus groups did not function as intended – they were more structured than intended and relied heavily on researcher prompts. This may explain why no new themes were identified in the focus group data as the researcher prompts had been influenced by existing themes from the survey data.

4.2 Recommendations and future work

The results of this study highlight the importance of providing appropriate support for students undertaking peer reviews for the first time – both in terms of a scaffold to structure their feedback, and training to help students see how an 'expert' would approach the task. By providing this additional support, students may become more confident in their ability to provide peer feedback. It is also important to be clear with students about the benefits of engaging with peer reviews compared to only receiving staff feedback to maximise their engagement with the process.

The Engineering by Investigation unit was modified in 2022/23. The overall peer review process was maintained, but additional 'training' was provided in the form of staff demonstrating giving feedback to sample reports before each peer review. The structure of the peer review questions was modified to reduce the number of open-ended questions reviewers needed to answer, as novices are more comfortable with closed questions (Nilson 2003). A self-review task carried out with group discussion also replaced one of the four peer review tasks, in an attempt to maintain student engagement and make explicit the link between providing feedback and making changes to their own work. Evaluation of these changes is ongoing, but initial results suggest students have been more engaged and more confident while providing peer feedback.

5 CONCLUSION

This project gathered data about student perceptions of peer review through surveys and attempted focus groups. Results showed an overall appreciation of the benefits of peer review and the structure of the process used in the unit. Staff perceptions of student reluctance to engage in the process was likely due to low student confidence in giving peer feedback. This has been addressed by providing additional training and support for students engaging in peer reviews for the first time within the unit.

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WHAT DO ENGINEERS DO WITH WHAT THEY KNOW?: OBSERVING SPECIALISED TECHNICAL KNOWLEDGE IN PRACTICE

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ABSTRACT

The gap between engineering education and practice has been subject to considerable research attention. We look at studies of engineering practice with a view to informing education. Our interest is in identifying technical knowledge and how it is used in practice, as well as what kind of technical knowledge is used but not taught. This paper seeks to systematically review the existing literature on engineering practice, drawing from and adding to a prior data set developed by Andrea Mazzurco and colleagues, who found that there was a gap in studies of specialised technical knowledge in practice. Investigating their dataset we found that rather than being absent, studies of practice have tended to background knowledge, by focusing on professional skills and attributes and obscuring the role of specialised technical engineering knowledge. In engineering education and practice, surveys of ‘what graduates need’ tend to separate out graduate attributes from specialised engineering knowledge; however, detailed, qualitative studies show the extent to

which these graduate attributes are intertwined with specialised knowledge. This paper focuses on research studies that include an observational component. In total, 23 papers were analysed with a view to answering the research question: what do observational studies of engineering practice tell us about specialised engineering knowledge? We examine how knowledge was constructed by the authors, usually as socially mediated and embodied; but also at how knowledge was used by participants, generally as foundational to reasoning but in tacit ways.

1 INTRODUCTION

The gap between engineering education and practice has been the subject of considerable research attention. In this paper, we look at studies of engineering practice with a view to informing education. Our interest is in identifying technical knowledge and how it is used in practice, as well as what kind of technical knowledge is used in practice but not taught. The paper applies a systematic literature review method.

Several systematic reviews of the literature on engineering practice have already been conducted. Most notable for the purposes of this paper, the *European Journal of Engineering Education* published a review by Andrea Mazzurco and others (Mazzurco et al. 2021) that offers a mapping of the empirical research on practising engineers and seeks to develop an agenda for research on engineering practice. Mazzurco et al. (2021) analysed almost 200 peer-reviewed journal articles published between 2000 and 2018 and identified five research themes within this literature. These themes pertain to: a) how engineers learn on the job, b) what competencies practising engineers require, c) what engineers actually do in practice, d) how diversity is experienced and managed in engineering practice, and e) how engineers experience and describe themselves and their profession.

For each of these research themes, Mazzurco et al. (2021) synthesise what the existent literature offers, but also identify gaps in the literature pertaining to each theme. They find that the literature on engineering practice focuses to a large extent on what have variously been called 'soft skills' (Caeiro-Rodríguez et al, 2021), generic competencies (Male, 2010), professional skills (Winberg et al, 2020), or non-technical skills. This literature generally finds that soft, generic, professional or non-technical skills and competencies are integral to the practical accomplishment of engineering work.

While we recognise the importance of these studies, we argue that these professional competencies are founded on specialised knowledge (cf. Martin et al. 2005). Our purpose therefore is to pull together the literature that looks beneath professional competence to the specialised knowledge that it is founded on. In so doing, we respond to the work done by Mazzurco et al. (2021) who identify one of the gaps in the current literature as pertaining to understanding how technical (or specialised) knowledge is used in engineering practice. Investigating their dataset, we found that rather than being absent, studies of practice have tended to background knowledge by focusing on professional skills and attributes and obscuring the role of specialised technical engineering knowledge. What is clear in the literature is that technical knowledge is broader than abstract theoretical knowledge, spanning knowledge of both theoretical concepts as well as knowledge of specialised technological artefacts intrinsic to engineering.

In engineering education and practice, surveys of 'what graduates need' tend to separate out graduate attributes from specialised engineering knowledge; however, detailed, qualitative studies that employ ethnographic methods tend to better show the extent to which these graduate attributes are intertwined with specialised knowledge. Therefore, this paper focuses specifically on research studies that include an observational component. In total, 23 papers were analysed with a view to answering the research question: what do observational studies of engineering practice tell us about specialised engineering knowledge? We examine the problems and frameworks such studies lend themselves to, as well as how knowledge is constructed within these studies, both by the authors but also by the participants being observed.

We argue that it is important to investigate how technical, or specialised, engineering knowledge is taken up and used in engineering practice, as this may have significant implications not just for what specialised knowledge needs to be covered in the engineering curriculum, but also for how such specialised knowledge might be developed. This paper seeks to review the existing literature, to begin to address the knowledge gap identified in Mazzurco et al. (2021), and as a point of departure for initiating a process of understanding how specialised knowledge is deployed in engineering practice, and the implications this may have for engineering education.

2 METHODS

Systematic literature reviews have existed for some time and have been widely used in various disciplines. However, they are a relatively new inclusion in engineering education research (Borrego et al. 2014). Nonetheless, systematic reviews of the literature can and do fulfil important functions within this area of research: synthesising prior work, informing practice and identifying new areas for research (Borrego et al. 2014). Traditionally, a systematic literature review is conducted by using key search terms and criteria in a particular database or journal, or set of databases or journals, and appraising all of the articles in that set that meet the search terms and criteria (Grant and Booth, 2009). As the methodology has grown in use, various approaches to systematically reviewing extant literature on a topic have been developed (Grant and Booth, 2009). In this paper, we make use of the data set developed by Mazzurco et al. (2021). This is because their data set was made publicly available and has already identified the relevant literature pertaining to engineering practice published between 2000 and 2018. As such, we used this existing data set and identified those texts within it that dealt with the question of specialised knowledge. This reduced their data set from 187 texts to 64 texts. Below, we list the specific exclusion criteria applied. In addition, because the Mazzurco et al. (2021) study had only included literature published between 2000 and 2018, we repeated their search exactly, but for 2019 and 2020. This yielded an initial total of 991 search results, of which all but 21 were subsequently excluded by identifying only those studies that related to the nature and function of studies that related to the nature and function of specialised engineering knowledge in engineering practice, including those that did not explicitly focus on knowledge but in which specialised knowledge was evident, including those that did not explicitly focus on knowledge but in which specialised knowledge was evident. This meant that a total of 85 texts were found to be concerned, at least in part, with specialised or technical engineering knowledge in practice.

To limit the data set to be analysed in a systematic literature review, various exclusion criteria can be applied. These often pertain to exclusion of material published outside of a particular time period. As already noted, Mazzurco et al. (2021) focused their analysis only on material published between 2000 and 2018, and we replicated their search exactly but for 2019 and 2020. Exclusion criteria can also pertain to the content of the material found through successive rounds of title, abstract and full-paper review aimed at excluding paper results that prove not to be relevant to the analysis. This was done in Mazzurco et al (2021) and further undertaken in this study. Table 1 lists the exclusion criteria applied to arrive at the final data set of 85 studies. It should be noted that some texts were excluded on more than one basis. The exclusion criteria were applied by one of the researchers and this was then checked by a second researcher.

Table 1. Exclusion criteria

Exclusion Criteria	Mazzurco et al (2021) data set	Additional 2019 and 2020 data
Initial Total	187	991
Clearly natural or engineering science papers (not related to engineering education or practice)	0*	793
IT & software engineering, machine learning and programming	19	39
Not in the english language	0*	2
OTHER not related to engineering	0*	27
Focus on education: Learning with technology	0*	3
Focus on education: K12 schooling	0*	11
Focus on undergraduate teaching & learning	4	64
Focus on work-integrated learning at undergraduate level	0*	5
Focus on education: social and psychological factors (incl. retention)	0*	7
OTHER focus on knowledge and skills in academia, not in practice	0*	2
General professional competencies or attitudes, rankings or competency gaps	24	6
Workplace learning but not knowledge	7	1
Detailed studies of other generic competencies (eg management, teamwork, communication, ethics, design processes)	22	15
Accessing, using or transferring information, not knowledge	13	2
Competencies, with mention of knowledge but not focused on nature of knowledge (eg. lists of knowledge content or knowledge as a competency, surveys of individual needs)	3	8
Social (or philosophical), identity, disposition/attitudes, gender/sex in the workplace	22	22
OTHER focus on practice-based competencies but not knowledge	17	18
REMAINING INCLUSIONS	64	21
Observations	23	0

* These had already been excluded by Mazzurco and colleagues.

The 85 papers identified as speaking to specialised technical knowledge in engineering practice were subsequently grouped according to the methods used. In this paper, we only discuss the 23 papers that included an element of observation (of engineers in practice) as part of their research design and as reported on in the papers. The full data set is still being analysed as part of a broader systematic literature review. In this paper, we seek to answer the more specific question: what do observational studies of engineering practice tell us about the nature and function of the nature and function of specialised engineering knowledge?

The included papers were each read by at least two of the authors, who answered the following questions about each paper:

1. What is the problem or issue being addressed?
2. What is the work context (design office / supply / service etc)?
3. What conceptual or theoretical tools are used?
4. What is the focus / is knowledge foregrounded or backgrounded?
5. What methodology is used?
6. What are the key findings?
7. What implications for engineering education are drawn, if any?
8. How is knowledge constructed by the authors of the paper?
9. How is knowledge used by the participants in the research?

The answers to these questions were then grouped thematically and are reported upon in the findings and discussion that follows.

3 FINDINGS

Observational studies of engineering in practice are aimed at an array of problems or issues. Studies explicitly focused on specialised technical engineering knowledge included those aimed at understanding the use of concepts in practice (Bornasal et al. 2018), the use of systems engineering knowledge (Brooks, Carroll and Beard, 2011), and the use of mathematical knowledge in practice (Gainsburg, 2007). Other studies situated knowledge in social relations; such studies focused on newcomer participation in the engineering workplace (Johri, 2012), on graduate underpreparedness (Buch 2016), on how engineering teams share knowledge between specialities within work organisations (Baird et al. 2000; Darr 2000; Bechky 2003; Maaninen-Olsson et al. 2008; Ratcheva 2009), and on how knowledge is shared between and across projects (Koch 2004), particularly where teams are distributed geographically (Larsson 2007). A third set of studies focus specifically on the materialisation of knowledge in engineering practice, such as in the form of objects (Lee and Amjadi 2014) and in machinery and equipment (Styhre et al. 2012). Still further studies focus on how the enactment of engineering work relies on the combination of the social, the material and the embodied (Trevelyan, 2007; Trevelyan 2010; Reich et al. 2015). Because of the nature of this particular subset of the literature, some studies also seek specifically to make a methodological contribution (Baird et al. 2000; Suchman. 2000; Trevelyan. 2016). One study’s aim aligned closely with our own aim in conducting this systematic review:

despite calls for studies of engineering to pay attention to the kinds of knowledge that engineers employ, few studies have conducted detailed investigations of knowledge use in everyday engineering. As a result, the question of whether historically established or practice-generated knowledge is more instrumental in engineering work remains unresolved (Gainsburg et al. 2010:198).

The contexts in which these observations were conducted included distributed design offices contracting to RollsRoyce (Baird et al. 2000), high-tech manufacturing companies (Bechky 2003), transportation engineering consulting firms (Bornasal et al. 2018), government enterprises (Brooks et al, 2011), an engineering consultancy company with a focus on climate change (Buch, 2016), a microelectronics company (Darr 2000), structural engineering design offices (Gainsburg 2007), a research and development laboratory (Johri 2012), a major automotive company (Larsson 2007), a public medical service (Maaninen-Olsson et al, 2008), an international wafer manufacturing company (Lee and Amjadi 2014), a multinational telecommunications company (Styhre et al. 2012), and a state agency engaged in designing a bridge (Suchman 2000). The location for the research was largely the global North and West (the United States, the United Kingdom, Sweden, Denmark, Australia). One exception to this was research conducted in Taiwan (Lee and Amjadi 2014).

Methodologically, the papers were all selected because they included an observational component. However, most of the studies also incorporated other data collection techniques. Also, observation tends to be a hallmark of ethnographic research - but not all the studies included in this review labelled themselves as ethnographic in nature, though several did (Baird et al. 2000; Darr. 2000; Suchman 2000; Bechky 2003; Collin 2006; Gainsburg 2007; Larsson 2007; Johri 2012; Reich et al. 2015; Bornasa et al, 2018). Several studies were identified as using a case study approach (Maaninen-Olson et al. 2008; Brooks et al. 2011; Lee and Amjadi 2014), some with ethnographic elements (Koch, 2004; Styhre et al, 2012). The remainder of the papers were not located in any broad methodology but, in addition to observation, included several other research methods, including interviews (most of the studies), document and other artefact analysis (Bechky 2003; Ratcheva 2009; Brooks et al, 2011; Lee and Amjadi 2014; Bornasal et al. 2018), participant diaries (Johri 2012) and focus group interviews (Reich et al, 2015).

Where the theoretical and/or conceptual bases of the papers were made explicit, these tended to fall in three broad categories. A number of studies located themselves in relational, situated and/or sociomaterial approaches (Suchman 2000; Bechky 2003; Ratcheva 2009; Styhre et al. 2012; Bornasal et al. 2018). These approaches view knowledge as situational, cultural and contextual and locate knowledge within broader social and material systems. They share a view that “meaningful and effective knowledge of concepts may be more fully understood when we consider what concepts mean, why they are relevant to a community, and how they are useful to a community" (Bornasal et al. 2018: 321), and a focus on knowledge not “as a self-standing body of propositions, but identities and modes of action established through ongoing, specifically situated moments of lived work, located in and accountable to particular historical, discursive and material circumstances" (Suchman 2000: 312-313). Another common theoretical and conceptual framework employed were practice accounts of engineering work, in particular the work of Schatzki (2002; 2006; 2012) and that of Lave and Wenger (1998). These studies tended to focus on the everyday practices of engineering professionals as they engage in activity in their workplaces (Koch 2004; Larsson 2007; Maaninen-Olson et al. 2008; Johri 2012; Lee and Amjadi 2014; Reich et al. 2015; Buch 2016). These approaches view knowledge as visible in and emergent from practice, and contend that “knowledge is created and used in ‘continuous’ knowing processes” (Maaninen-Olson et al. 2008: 261). A third category of frameworks employed are systems perspectives (Baird et al. 2000; Brooks et al. 2011). These approaches are ecological in focus and draw on the idea of systems engineering methods. Other approaches drawn on include interpretive frameworks (Darr 2000; Trevelyan 2007; Trevelyan 2016), the concept of mathematical dispositions (Gainsburg 2007), and a behavioural approach (Gainsburg et al. 2010).

4 DISCUSSION

A minority of the studies in our review view knowledge from a knowledge management perspective (Baird et al. 2000; Maaninen-Olson et al. 2008; Ratcheva 2009). These studies tend to either view knowledge as a black box, thus not theorising it in any way (Ratcheva 2009), or to reify knowledge as something that can be ‘transferred’ or ‘shared’. For example, Baird et al (2000) find that technical information and data about products, including experience of past successes and failures (what we would view as experiential knowledge) is informally transferred through conversations within informal social networks. However, Maaninen-Olson et. al (2008), despite locating their research in a knowledge management perspective specifically argue that knowledge is connected to context and that it should not be viewed as an independent object. Instead, they argue, knowledge is distributed in tools and artefacts

Indeed, the view that knowledge is distributed - in people and in objects - was prevalent in our study. Bornasal et al. (2018) argue that conceptual knowledge is distributed in the world and facilitated around material resources. Similarly, Lee and Amjadi (2014) argue that objects trigger meaning-making (which facilitates problem solving in engineering), foster spontaneous relationships (which encourages cooperation and negotiation) and engender real-time exploratory action (which expedites troubleshooting processes). In so doing, they use the concept of knowing through objects to describe the role that objects play in engineering work. Styhre et al. (2012: 151) show how “engineering work is based on distributed know-how and joint collaborations, emerging as a patchwork of activities where one single person may know a lot, but not everything, about the technology-in-the-making”.

Another characteristic of knowledge prevalent in our review is the view that knowledge emerges through participation and interaction within a joint enterprise (Johri 2012). As Bornasal et al. (2018: 321) argue: “knowledge becomes a dynamic reconstruction of a world that is dependent on participation and interaction within a community". Johri uses the view of knowledge as both distributed and socially-mediated to show that newcomers into an organisation make use of both social (interpersonal) and material (information technology) resources to create sociomaterial assemblages that foster success in moving toward full participation in the organisation. Similarly, Bornasal et al. (2018) find that engineers expand their individual understandings of a concept by engaging in social negotiation of meaning.

These findings related to knowledge have two important implications. The first of these is that knowledge is transformed, rather than transferred, through socially-situated sharing. Bechky (2003) shows this in their finding that members on a production floor worked to transform the understandings of others in order to generate a richer understanding of production problems. This, Bechky (2003: 317) argues, “generated a more broadly shared understanding that allowed for the knowledge to be used across the organization”. A second implication is that specialised engineering disciplinary knowledge bodies, such as mathematics, are embedded in knowledge but are not knowledge in themselves. Gainsburg (2007) argues that mathematics is a tool (used sceptically with reverence) recruited for the purpose of making design decisions (in the form of engineering judgement) towards the production of something other than knowledge. As Gainsburg (2007: 498) explains:

Mathematics is the mandatory language for design and analysis and mathematical proof the industry standard for final justification. The end products of structural work are a symbolically expressed design and a story about how that design came to be. That story, told through calculations and mathematical proof, is a dramatically revised history of the design process, one that erases nearly all traces of iterations, missteps, and rejected methods, many of the modeling assumptions, and some instances of engineering judgement.

A final key perspective that emerges from the papers included in our dataset is the view that knowledge is socio-culturally regulated (see, for example, Brooks et al, 2011). Koch (2004) shows how knowledge-sharing can be hindered by organisational cultures when a culture of ‘getting things done’ – what Koch (2004) terms the tyranny of projects – cross-project learning and knowledge sharing are hindered. A key implication of this is outlined by Trevelyan (2007), namely that a large part of the work of the engineer is technical coordination, which Trevelyan (2007: 194) defines as “working with and influencing other people so they conscientiously perform some necessary work in accordance with a mutually agreed schedule”.

5 CONCLUSIONS

The papers included in our dataset present several implications for engineering education. They demonstrate what many engineering educators have long argued: that knowledge is more than mere content, that it is embedded in the artefacts and everyday activities of engineering, and that knowledge is distributed among people and artefacts and, as such, socio-culturally mediated. A majority of the papers surveyed call for greater focus on engineering in context. For example, Bornasal et al. (2018:319) suggest “activating and developing students’ knowledge of concepts with regard to the complexities of real-world contexts [in order to] bridge the gap between the classroom and the workplace”. Similarly, Gainsburg (2007) identifies a need to “present a more realistic view of the role of mathematics in everyday occupations and to counter the damaging perception of mathematics as quasi-divine”. This can be achieved through “solving a nonmathematical, real-world problem, rather than doing or learning mathematics per se”.

This has implications not only for curriculum design and pedagogy, but also for the way we frame how engineering work is understood for students. Some papers argue against the individualised view of the engineer as the ‘hero’ designer, as this is counterfactual to the way engineering knowledge is produced, shared and disseminated in engineering practice. For example, Trevelyan (2007) argues that the "notion that an engineer has to be engaged in technically challenging work to create value … seems to be a pernicious misunderstanding that can undermine many engineers' self-esteem". This would suggest that engineering curricula should foreground the social, material and distributed nature of knowledge in practice.

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INTERCONNECTEDNESS OF GEOMETRIC, LINGUISTIC AND ALGEBRAIC THINKING IN STUDENT PERFORMANCE MEASURES: AN ASSOCIATION RULES APPROACH

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ABSTRACT

Assessing student performance is crucial in education for evaluating knowledge acquisition and competency development. Traditional grading systems often overlook the interconnectedness of learning domains, which can provide valuable insights into student understanding. This study investigates the associations between geometric, linguistic, and algebraic thinking and their impact on student performance measures and grading using association rules.

We analyzed a dataset comprising student responses to geometric, linguistic, and algebraic questions by applying association rule mining techniques. The extracted rules were used to evaluate question similarity, revealing deeper insights into student performance and problem-solving strategies.

Our findings demonstrate significant interconnectedness between geometric, linguistic, and algebraic thinking, with implications for student performance measures and grading. Students' ability to solve problems in one domain often translated into enhanced performance in others, suggesting a shared set of cognitive resources and strategies. Association rules proved valuable for identifying nuanced relationships between question types and domains, providing a comprehensive perspective on student performance.

These results have important implications for educational practices, emphasising the need to consider the interconnectedness of learning domains when designing assessments and grading systems. By adopting a holistic approach to student evaluation, we can better support students' development of critical thinking and problem-solving skills across various domains, fostering deeper subject matter understanding and enhancing educational outcomes.

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1 INTRODUCTION

1.1 Problem

The evaluation of student performance has long been a central concern for educators and policymakers, particularly at the beginning of university studies when students face new academic challenges and may experience a higher risk of dropout. Accurate assessment of student performance is vital for several reasons, including providing targeted support to students who may be struggling, identifying talented individuals who could benefit from extra- curricular opportunities, and ultimately improving retention and academic success rates. In this context, our work examines the need to measure student performance early in their university careers and explores innovative methods to achieve this goal.

One of the primary reasons for assessing student performance at the onset of higher education is the high dropout rate observed in many countries, including Hungary. Early identification of students at risk of disengaging from their studies can facilitate timely interventions, helping to prevent attrition and promote academic achievement. By understanding the unique challenges faced by students in the transition to university life, educators can tailor support services and resources to maximize student success.

In Hungary, university admission scores are primarily based on high school final exam scores, which are not field-specific. This approach may not accurately predict a student's aptitude or preparedness for their chosen field of study, leading to potential mismatches between students' abilities and the demands of their academic programs. An improved method of assessing student performance that accounts for field-specific knowledge and skills could better align students with appropriate courses and facilitate smoother transitions into higher education.

1.2 Interconnectedness

The research question aims to explore how student test results can reveal the interrelationship between different areas of knowledge or skills. By providing layered responses during the evaluation of test results, a more precise understanding of the studied population can be obtained, and previously unknown hidden connections, such as those between mathematics and language, can be uncovered. This research question seeks to enhance the discovery of complex connections and relationships, contributing to a better understanding of student performance.

To address these issues, our study proposes a novel approach to evaluating student performance that takes into account the interconnectedness of learning domains. By identifying and leveraging associations between geometric, linguistic, and algebraic thinking, we aim to provide a more comprehensive understanding of student performance across multiple subject areas. The insights gained from this analysis can be used to design targeted interventions, such as offering extra-curricular classes for talented students or providing additional support for those who may be struggling.

In conclusion, the accurate and timely assessment of student performance at the beginning of university studies is crucial for supporting students' academic success and reducing dropout rates. By adopting a holistic approach that considers the interconnectedness of learning domains, we can better align students with appropriate courses, foster deeper subject matter understanding, and ultimately enhance educational outcomes.

2 METHODS

We applied association rules which are developed for the analysis of consumption patterns. To our knowledge, this method has not been used for the analysis of educational data. This allowed us to use a methodologically new tool to answer our research question.

2.1 Tests

Our research group focuses on creating entrance tests that accurately predict student performance and identify those needing extra support or talent development courses. By combining mathematical tests with language tasks, we can reduce learning bias-related distortion. A large student sample showed that language tasks help predict dropout rates and poor performance more precisely. Students excelling in both math and language tests tend to perform well in calculus subjects. Language tests, less dependent on grammatical knowledge, offer a more inclusive assessment of students' abilities.(Sipos et al. 2021)

The evaluation of geometric thinking was conducted using the van Hiele test (Senk 2022), while the assessment of linguistic and algebraic/reasoning abilities was performed through our custom-designed test. The van Hiele test consists of 25 questions, grouped in sets of five, whereas our test contains 14 questions related to mathematics and 31 linguistic/logic questions. (Olah e. al. 2019, Sipos snd Szilágyi 2022)

2.2 Association rules

To investigate the interconnectedness and correlation between questions in our test suite, we employed association rule mining, a widely recognized method for analyzing consumer behaviour. Association rule mining (Hipp 2000) is a powerful technique for discovering relationships and patterns among variables in large datasets. It has been particularly successful in market basket analysis, where it is used to identify items frequently purchased together. In our study, we applied this method to explore relationships between geometric, linguistic, and algebraic thinking questions.

Association rule mining relies on three primary measures: support, confidence, and lift. These measures provide valuable insights into the strength and relevance of the discovered relationships. Support refers to the proportion of the dataset in which an association rule is found to be true. A higher support value indicates that the rule occurs more frequently and is therefore more significant.

Confidence measures the likelihood that a particular association rule holds true. It is calculated as the ratio of the support of the entire rule to the support of its antecedent (i.e., the first part of the rule). A higher confidence value suggests a stronger relationship between the items in the rule. Lift is a metric that quantifies the improvement in prediction brought about by the association rule. It is calculated as the ratio of the confidence of the rule to the support of its consequent (i.e., the second part of the rule). A lift value greater than 1 indicates a positive association between the items in the rule, while a value less than 1 suggests a negative association.

In our analysis, we treated the solved questions as customer baskets. We applied association rule mining to these baskets to identify patterns and relationships between the different types of questions using the apriori algorithm provided in

‘arules’ package (Hahsler, 2005) version 1.7-6 in R (version 4.2.1). By uncovering these associations, we aimed to gain deeper insights into students' problem-solving strategies and performance across the geometric, linguistic, and algebraic thinking domains. The results of this analysis were used to refine the test suite, enhancing its efficiency and effectiveness in assessing student performance.
Association rules have limitations regarding large datasets and sparse data, which can affect the validity of results. This method primarily suits categorical or binary data, necessitating the conversion of continuous data into categorical by discretization.

3 DATA

The dataset used in this study was collected from 153 students who began their studies in 2020 in Mechatronics Engineering or Energy Engineering programs. Mechatronics Engineering requires the highest admission scores in Hungary among all engineering disciplines, while Energy Engineering also demands high admission scores. As a result, the two groups of students can be considered more talented than the average engineering student population.
Despite their high admission scores, the students in our sample exhibited diverse high school backgrounds. Some students had taken advanced-level mathematics courses in high school and completed advanced-level final exams, while others pursued advanced-level final exams in different subjects. This variation in prior knowledge has led to significant differences in mathematical proficiency among students, posing challenges in building a solid foundation in math for more engineering-oriented subjects.
Our dataset includes information on each student's performance in the geometric, linguistic, and algebraic thinking questions from our test suite. By analyzing this data using association rule mining, we aimed to identify patterns and relationships between the different types of questions and uncover insights into students' problem-solving strategies and performance across the three learning domains. This information can then be used to inform targeted interventions and support services, helping to bridge gaps in knowledge and ensure that all students can succeed in their engineering studies.

4 RESULTS

Upon analyzing the dataset, we observed that certain questions were solved by almost everyone, such as a question involving logarithmic equations or deciphering the meaning of a Latin word from a few Latin sayings containing the word. With over 94% of students successfully answering these questions, the information gain from these items was limited.

To focus on more informative associations, we narrowed our analysis to rules with low support (0.4) and high lift values. High lift values allowed us to identify relationships between similarly solved questions. Relying solely on correlation was insufficient due to the excessive noise (sometimes students make random mistakes), so the lift metric was employed to derive more meaningful insights.

It is important to note that the number of possible rules in our analysis was very high, while the number of observations (i.e., students) was relatively low. Consequently, we limited the maximum number of questions in one rule and used different support thresholds compared to those typically employed in other fields where the number of observations is much higher. By adjusting our analysis parameters to suit the unique characteristics of our dataset, we were able to uncover valuable information about students' problem-solving strategies and performance across the geometric, linguistic, and algebraic thinking domains.

4.1 Findings

The analysis of our dataset revealed several key findings about the relationships between different types of questions and the performance of students across geometric, linguistic, and algebraic thinking domains.

Questions from the same math subfield exhibited strong correlations: For instance, solving four of the last five van Hiele questions demonstrated a strong association with solving difficult geometry questions in our test. This suggests that students who perform well in one aspect of a math subfield tend to excel in other related problems within that subfield.

Connections between seemingly unconnected fields were identified: An interesting association was observed between solving the last van Hiele-level questions and finding synonyms in the linguistic portion of the test. This finding implies that there may be underlying cognitive strategies or abilities that are shared between geometric and linguistic thinking.

Advanced-level final exams and taking advanced math classes in high school not only led to better procedural math skills but also showed a strong positive correlation with several linguistic questions: Students with advanced math backgrounds performed better on tasks such as identifying the non-fitting word from a list or finding a word that could create a new complex word when combined with a list of words. This result suggests that there may be transferable skills or knowledge gained from advanced math coursework that also benefits linguistic performance.

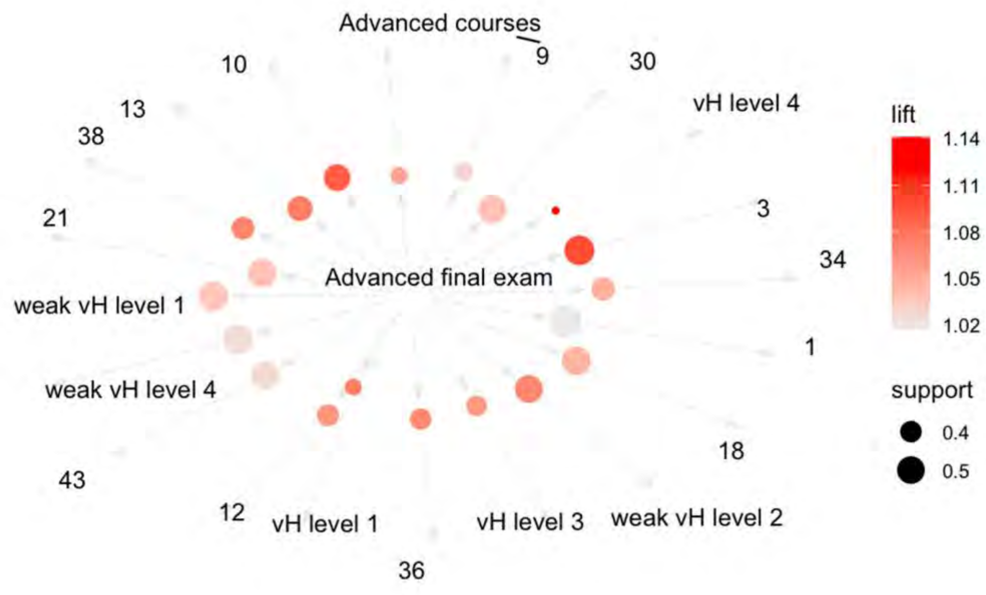

Fig. 1. The top 20 association rules with the highest lift value where the advanced level final exam is the antecedent (LHS).

Equations with real numbers and filling out missing chunks of text: Our analysis revealed a relationship between solving equations with real numbers and completing text-based tasks that require filling in missing portions. This finding indicates that students who are proficient in algebraic thinking may also possess strong linguistic skills or vice versa, further highlighting the interconnectedness of learning domains. These results underscore the importance of considering the interconnectedness of learning domains when designing assessments and grading systems. By recognizing the complex relationships between different subject areas, educators can better support the development of critical thinking and problem-solving skills across various domains, ultimately enhancing educational outcomes for all students.

5 CONCLUSION

We aimed to employ association rules, commonly used in commerce and economics, to analyze educational data and map the relationship between students' knowledge in different areas. This approach allowed for a more sophisticated assessment of student knowledge.

Our findings demonstrate that association rules can effectively generate valuable insights into the relationships between questions in tests, shedding light on the interconnectedness of learning domains. However, there are several limitations to this approach. One significant challenge is the manual parameter tuning required for association rule mining, which can be labour-intensive and time-consuming. Additionally, the limited number of samples in our dataset restricts the confidence we can place in the discovered rules. A larger dataset would enable more robust and reliable results.

Despite these limitations, our study provides a novel approach to assessing exam data with potential applications in improving the testing process. By using the insights

gained from association rule mining, educators can streamline examinations in two main ways:
Eliminating redundant questions: By identifying questions that are solved by almost everyone or removing highly correlated questions, the test can be shortened without sacrificing its ability to evaluate students' knowledge and skills effectively.
Implementing adaptive testing: Our findings can inform the development of an online exam system that recommends questions based on students' previous answers. This approach allows for the acquisition of more information about student performance within the same number of questions, optimizing the test-taking experience for both students and educators.
Future research could focus on expanding the dataset to include more students and diverse educational backgrounds, which would enhance the generalizability and reliability of the association rules. Additionally, further exploration of adaptive testing approaches and the development of algorithms to automate parameter tuning in association rule mining could lead to more efficient and effective assessment methods, ultimately benefiting both students and educators in the long run.
Another significant advantage of using association rule mining to analyze test data is its potential to differentiate more effectively between students. By identifying patterns and relationships between different types of questions and learning domains, educators can gain a deeper understanding of each student's strengths and weaknesses. This information can then be used to develop personalized learning plans, tailored interventions, and targeted support services to address individual needs and promote academic success.
Moreover, by incorporating adaptive testing strategies based on the insights gained from association rule mining, exams can be tailored to challenge and engage students at various ability levels. This approach not only provides a more accurate assessment of each student's performance but also fosters an inclusive learning environment that accommodates diverse learning needs.
In summary, utilizing association rule mining in conjunction with adaptive testing methods can help educators differentiate between students more effectively, ultimately enabling them to provide targeted support and personalized learning experiences that cater to individual strengths, weaknesses, and learning styles. This approach not only enhances academic outcomes but also promotes equity and inclusivity in education.
The association method is particularly well suited for analysing the results of complex tests in areas requiring a high degree of knowledge transfer, such as engineering education. For example, it can be used to investigate how knowledge of eigenvectors and eigenvalues in linear algebra is used to understand the stress tensor in material structure. Open-source software like R makes the method accessible to all. This not only allows us to quantify the effectiveness of learning and teaching but also to explore various previously unknown relationships.

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SUSTAINABLE ENGINEERING EDUCATION EMBEDDED CURRICULA RESEARCH PROJECT

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***Conference Key Areas**: Embedding Sustainability and Ethics in the Curriculum and Curriculum Development.*

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Keywords: *Engineering Learning Curricula, Sustainability, UN Sustainable Development Goals, Research Project, Fundamental Human Need satisfaction, Knowledge creation*

ABSTRACT

A previous conference paper with case study report findings began this research so as to inform and be of use to the International Association for Continuing Engineering Education (IACEE) institutions and its membership on the importance of embedding sustainability in all engineering education courses from the beginning to the end of the Degree and beyond into Continuing Engineering Education (CEE) . This present project continues to qualitatively research and investigate the extent to which and how Engineering Learning Curricula (ELC) incorporate and embed sustainability as central to the future work practice of all engineers. Specifically, as the project takes a more comprehensive and longer-term approach to be of ongoing use to all engineering education faculties and institutions, corporate and government policy development, as well as Continuing Engineering Education (CEE) providers. This research uses the digital platform of Sustainability Education & Research IN Action (SERinA), an IACEE Global Initiative, as a future database reporting on best ELC practices in all forms of Engineering Education and post-CEE practice. IACEE's academic engineering member organisations, member institutions, and other engineering institutions outside of the IACEE will be incorporated in the long term into this research project. Initially, information will be obtained via each institution's external website and its academics for this research project and this report paper. This project will also, in the future, seek to interview graduate engineering students on how effective their degrees were in embedding sustainable learning understandings useful in their post-graduate world of engineering practice.

1 INTRODUCTION

The Brundtland Commission's report defined sustainable development as : *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (WCED n.d.). This underpins engineering students' need to develop critical thinking approaches to their future work practice and environment, as "Sustainability for the planet is not a sideshow," particularly within everyday engineering practice (la Grange, Smith, and Soeiro 2022). Critical thinking presupposes assent to rigorous standards of excellence and mindful command in engineering practice via effective communication and problem-solving. Currently, the most commonly accepted way of assessing the impact, quality, and reputation of universities and other higher education institutions is the Global Ranking of Universities (GUR). However, concerning the contribution of academic institutions to sustainable development, one of the most important measurements is expected to be the Quacquarelli Symonds (QS) World University Ranking®. Since starting in 2023, this ranking will evaluate two new categories: social impacts and environmental ones (QS 2023). Furthermore, in 2010, the University of Indonesia launched the ambitious UI GreenMetric Project to measure the direct impact generated by sustainability strategies in universities. The UI GreenMetric allows us to know each university's regional and global efforts and the effects of each sustainability strategy (UI GreenMetric 2022). On the other hand, The Times Higher Education (THE) Impact Rankings assess universities against the UN Sustainable Development Goals (SDGs) in four areas, namely research, stewardship, outreach and teaching. In the fifth year, THE Impact Rankings reached to 1,591 universities from 112 countries/regions in 2023 (THE, 2023).

It is a fact that engineering is about the scientific knowledge and practice of solving problems. So far, it plays a significant role in the survival of humankind and improving the quality of life. Now the most critical problem for humankind is how to ensure sustainable development by preserving our planet. In this context, engineering has a significant role to play and the engineering education should contribute to this new role for realization of sustainability.

Creative problem-solving skills are needed to “evaluate the implications of their solutions beyond their immediate technical context" (la Grange, Smith, and Soeiro 2022). However, critical thinking skills and the ability to collect, evaluate, and utilize information are often not advanced in current engineering graduates. Engineers and engineering programs have played and will continue to play a crucial and pivotal role in assisting the global community in meeting fast-changing needs and the UN Sustainable Development Goals by 2030 (Soeiro, Smith, and Grange 2022). Therefore, sustainability thinking should become ingrained into the engineers` critical thinking of daily practice as a fundamental core value, just as safety has become a universal central tenant of engineering practice. This should begin immediately, from 1st year of learning as a student. To have the best chance of success, sustainability, in all of its emerging facets, must form an integral and critical thinking part of the mind and toolsets of engineers in all aspects of their education, research, and practice. For this to occur, this paper proposes that sustainability must become an essential and integral component of the education and training of engineers across all engineering curricula. Over many decades, there have been worldwide calls for the embeddedness of sustainable thinking and practice to be part of all engineering curricula and not just an add-on. This demands that Critical Sustainability Thinking become ingrained as a fundamental core value.

This all links with the IACEE Porto Declaration, challenging engineers, especially the IACEE’s members, to take this on board and become embedded in everyday practice and learning opportunities: *“In the IACEE World Conference held in May 2016 and under the theme “Innovation in Continuing Professional Development: A Vision of the Future” participants signed a declaration”.* The Porto Declaration then led to the creation of a database of best practices called SERinA (Sustainable Education Research in Action). This ongoing research project intends to post the findings and further research to be accessed within the SERinA website databases (International Association for Continuing Engineering Education n.d.).

2 RESEARCH AIM

The main research aim is to qualitatively research and investigate the extent to which and how Engineering Learning Curricula (ELC) incorporate and embed sustainability as central to the work of all engineers, be it in planning, practice, or policy, within both the private and public sectors. In the long term, it is intended to investigate via interviews with past students and now working engineers whether what they learned concerning sustainability at university is helpful in their everyday practice.

3 METHODOLOGY

This work in progress is part of a study that aims to determine via case studies, examples, and scenarios, allowing knowing and interpreting the positioning of educational institutions in the sustainability ecosystem. The research aims to provide descriptive information and enable a deeper understanding of global sustainability strategies. In addition, it analyses the actions and programs that different institutions are carrying out concerning sustainability.

4 RESULTS

Below are two case studies shared by academics involved in delivering each program and further examples of competence frameworks.

4.1 State University of New York – University at Buffalo (SUNY - Buffalo)

Sustainability efforts in practice are inherently broad. In a sense, this makes teaching challenging, for example, in an MS degree program, as postgraduate degrees are typically expected to add depth to a student's previously acquired knowledge base. At the State University of New York – University at Buffalo (University at Buffalo 2023), a 30-credit MS degree program has been created that provides the breadth and depth needed to satisfy the far-reaching diversity of sustainability content and the expectations for going deep into the content. This paper offers the program as a case study, including outcomes on admitted students and post-graduation career paths. SUNY-Buffalo is consistently ranked as one of the top global Universities for sustainability. The 2021 Times Higher Education Impact rankings associated with the United Nations Sustainable Development Goals listed the campus as #1 in the world for Climate Action and #2 for Affordable and Clean Energy. There is a culture of sustainability on and off campus, including faculty research, educational programming, and degree opportunities.

Recognizing that sustainability content is not "owned" by any single discipline, the degree is held within SUNY-Buffalo's School of Engineering and Applied Sciences. This facilitates the interdisciplinary training required to cover the breadth of topics needed – housing within a single department would tie students to introductory courses from that one program. Further, the degree allows students to take 20% of their credits (or even 30% with written approval) from outside the School of Engineering and Applied Sciences, adding even more flexibility. Sustainability conversations are most productive when they involve folks with different experiences and viewpoints. Again, this is counter to a typical MS program, where courses often have undergraduate-linked prerequisite training. To address this, along with the fact that many students crave sustainability content, the program casts a wide net in terms of recruitment and admittances. Not all students have an engineering BS degree and those that do come from Civil, Environmental, Mechanical, Aerospace, Chemical, Industrial, and Electrical Engineering backgrounds. Students without formal engineering BS training are expected to prove quantitative competence in their application. It is typical for the program's Director of Graduate Studies to discuss their case individually to ensure they will succeed in engineering courses. With that said, the program has admitted students with backgrounds in Mathematics, Chemistry, Biology, Environmental Geoscience, Accounting, Environmental Studies, and others. Breadth is provided through required courses. All students entering the program must take at least one Energy, Ethics, and Economics class. Specifically, when creating the program, new courses titled "Ethics of Engineering Sustainability" and "Economics of Engineering Sustainability" were designed to provide this critical content. These courses have students reading, thinking, discussing, and writing. They are not necessarily equation-based, pushing some engineers outside their math-centric comfort zones. They are taught by professors with unique training (e.g., philosophy, environmental economics, social justice, etc.) linked to their education, their research interests, or both. Depth is provided through elective courses and experiential learning. After required classes, students choose seven electives to fill out their degrees. They are encouraged to select these courses thematically, around broad topics such as Climate, Pollution, or Energy. A student focusing on Energy might, for example, choose classes such as Microgrids, Petroleum Engineering, Energy & Environment, and more – courses primarily housing in chemical and electrical engineering. A student focusing on Pollution will likely take environmental engineering courses, including Waste Management, Brownfield Remediation, Green Infrastructure, and Fate & Transport of Pollutants. Elective courses outside the School of Engineering and Applied Sciences are broad but have included popular classes from Urban and Regional Planning, Geography, Geology, Communications, and Operations and Logistics. Courses such as Geographical Information Systems and Industrial Ecology are recommended but not required for all students participating in the program. Significantly, every year the catalog of new classes grows – it is clear that students, including those from more traditional engineering MS programs, seek this sustainability content. Students are strongly encouraged to participate in experiential learning opportunities. Three credits (e.g., one class) are available for students completing a relevant internship experience, which the University/School/Faculty are happy to help them find. As a Research I institution, many students complete MS projects, providing 3 of their required credits. A study abroad opportunity is even available.

On average, the time to graduation has been between nine months and two years, with most students completing in 1-1.5 years. It is possible to complete the degree in two traditional semesters (i.e., nine months), although five graduate classes per semester can be daunting. Participation in research or mid-semester (as opposed to summer) internships will certainly slow time to graduation; those students will likely require at least three traditional semesters, often four. While it has not been quantified, student satisfaction with the program is high, and students have successfully launched (or continued) their careers post-MS degree. Graduates are entering into diverse fields, including regulatory (federal, state, and local levels), health & safety, consulting, industrial, waste management, water treatment, packaging, and more.

The logistics of a proper sustainability-focused graduate degree are challenging because such programming must be interdisciplinary, including many departments and faculty. These challenges are a requirement to make an adequate sustainability degree. That is to say, while there are many examples, it is challenging to “rebrand” an existing degree within a single department or program to all-the-sudden include sustainability. Far-reaching content not available in any one department is necessary. This can create ownership issues at a University (e.g., “Who gets the tuition revenue?”) and must be considered before initiation. At SUNY-Buffalo, degree ownership by the School instead of a Department made the program launch smoother, but issues with class registration/wait lists, sabbaticals, canceled classes, etc., remain. Finally, cohort development is challenging with students taking courses from many departments. Providing students with a home base is essential, possibly including invitations to departmental seminars and social events, faculty advisors, and more. This conflicts with the broad courses but helps create a more comfortable environment where they can build connections and friendships throughout the program.

4.2 Tecnologico de Monterrey

Regarding this institution, the document "Sustainability and Climate Change Plan 2025" and the results were consulted two years after its implementation (Tecnologico de Monterrey 2023b). According to UI GreenMetric, in 2022, Tecnológico de Monterrey was ranked 232nd, with the participation of 1,050 universities. Its highest score was in sustainability education and research, and its lowest was in water management. At the regional level, Tecnológico de Monterrey ranks 29th in Latin America and 11th in Mexico (UI GreenMetric 2022). Considering 2022 THE Impact Ranking, Tecnologico de Monterrey ranks between 100 and 200 with the participation of 1,410 universities; this position has been held for the past three years. The SDGs that have been best evaluated for Tecnologico de Monterrey are SDG5 (gender equality), SDG6 (clean water and sanitation), SDG11 (sustainable cities and communities), and SDG12 (responsible production and consumption) (Times Higher Education (THE) 2021).

Master in engineering management. There is growing interest in engineering to direct, identify, and effectively implement projects, considering legal and ethical principles, leadership, innovation, and sustainable development. This is further seen in large and multinational companies that also require engineers trained to be leaders of projects, with a mix of deep technical knowledge and soft skills. To meet these needs, the master’s in engineering management seeks to develop an engineer’s communication skills, leadership, and project management, combined with technical and analytical skills specialization to improve their work areas. The Master of Engineering Management is presented as an option, among other industry-oriented programs in Tecnologico de Monterrey, which focuses on different areas of engineering, with the primary objective to develop leaders and project managers, specialists in their area of expertise. This postgraduate program is designed for graduates with bachelor’s degrees in engineering and science, in which the goal is that students know and apply technology tools that help them manage and lead projects, responding to particular needs of the industry, thereby supporting the technological and economic development of the country, strengthening further the company-university relation. As part of the program, the student will carry out a project that meets a need or real problem of a company, where they apply and develop the knowledge and skills promoted by the program, which will be a graduation requirement (Tecnologico de Monterrey 2023a) .

4.3 Example of Competence Framework for Sustainable Construction Safety

The International Safety and Health Construction Coordinator Organization (ISHCCO) was founded in 2003 and is developing a qualification framework for occupational Safety and Health Construction Coordinators (SHCC). This framework meets European and national requirements for SHCC, as well as international requirements (ISHCCO 2023). Furthermore, the system developed by ISHCCO should enable benchmarking based on technical standards, on international and national criteria. For these reasons, the decision was made to deduce quality criteria from the European legislation and respective national implementations and support these with already established professional and international standards of the European Qualification Framework (EQF). The EQF is divided into three criteria for knowledge, skills, and attitudes regarding individual qualifications. In this detailed work, the existing and accepted standards from SHCC professionals were examined and compared with the contents of the European Directive 92/57 by institutions, companies, and educational and training organizations in Europe and the rest of the world. Furthermore, considering changes by UNSDGs to the construction sector, ISHCCO prepared a proposal to adapt the current IQF to include sustainability concerns about Ethics, Work, and Health. The main topics of the proposal address SDGs: 3: Good Health and Well-being; 4: Quality Education; 8: Decent Work and Economic Growth; 9: Industry, Innovation, and Infrastructure; 11: Sustainable Cities and Communities; 12: Responsible Consumption and Production; 16: Peace and Justice Strong Institutions; and 17: Partnerships to achieve the Goal. The adaptation of competencies reflects the needs of SHCC to acquire the knowledge, skills, and attitudes necessary to contribute towards the development of the goals effectively. The proposal also includes the recent implications provoked by the European Union - JRC "Green Comp Sustainability Competence Framework" publication. Finally, the proposal consists of suggestions on how these adapted competencies can be acquired by active SHCC and by future professionals in terms of training and education (Soeiro 2017).

4.4 GreenComp: The European Sustainability Competence Framework

Developing a European sustainability competence framework is one of the policy actions set out in the European Green Deal as a catalyst to promote learning on environmental sustainability in the European Union. GreenComp identifies a set of sustainability competencies to feed into education programs to help learners develop knowledge, skills, and attitudes that promote ways to think, plan, and act with empathy, responsibility, and care for our planet and public health. This work began with a literature review and drew on several consultations with experts and stakeholders working in sustainability education and lifelong learning. The results presented in this report form a framework for learning about environmental sustainability that can be applied in any context. In addition, the report shares working definitions of sustainability and learning for environmental sustainability that form the basis for the framework to build consensus and bridge the gap between experts and other stakeholders. GreenComp comprises four interrelated competence areas: embodying sustainability values; embracing complexity in sustainability; envisioning sustainable futures; and acting for sustainability. Each area consists of three competencies that are interlinked and equally important. GreenComp is designed to be a non-prescriptive reference for learning schemes fostering sustainability as a competence (Bianchi, Pisiotis, and Cabrera 2022).

4.5. Engineer Girls of Turkey (EGT) Project

Many statistics show that women are in minority in the field of science and engineering globally. According to the UNESCO Science Report 2021, women represent 33% of researchers, while only 28% of tertiary graduates are in engineering. Furthermore, women remain a minority in technical and leadership positions in technology companies (UNESCO, 2021). Nevertheless, recruiting and retaining a more diverse engineering workforce is utmost important to achieve UN SDGs and to ensure global gender equality.

In order to support the wider representation of women in the field of engineering professionally, Limak Foundation launched their flagship project, **Engineer Girls of Turkey** (EGT), in 2015 with the partnership of the Turkish Ministry of Family and Social Services, Turkish Ministry of Education and United Nations Development Program (UNDP) Turkey Office. The EGT Project consists of three programs for high schoolers, university students and corporate people.

The University Programme involves support for female students of engineering in computer, environmental, electrical-electronic, industrial, civil, chemical and mechanical engineering departments in Turkish universities. The university program includes scholarship and mentoring (by volunteer female professionals of engineering),besides the training program designed to promote their professional and soft skills and online English training. Additionally internship and employment opportunities at different companies are available.

Bogazici University Lifelong Learning Centre contributed to the development of the curricula and deliverance of courses. The curricula give a critical thinking and sustainability approach to the EGT fellows. The program also requires fellows to design and/or attend volunteering activities as a compulsory component of the program. Since the beginning, 710 female engineering students have benefited from the EGT University Program in 7 years (Limak, 2023). The program also extends its borders to Kuwait and Kuwait’s Engineer Girls project was initiated.

5 SUMMARY AND FUTURE DIRECTIONS

This study is part of broader research on integrating sustainability competencies, corporate social responsibility, and professional ethics in engineering degrees. Case study research included analysing teaching interventions over several years and a reflection process to provide proposals from different perspectives: curriculum, teaching practice, and institutional support. Civil engineers have a responsibility, as stewards of the built environment specific to civil infrastructure systems on which society relies, to ensure a sustainable future. Therefore, it is incumbent on engineers to provide a holistic approach to the management of infrastructure throughout its full life cycle participating in multi-disciplinary teams of professionals, including ecologists, economists, and sociologists, that effectively address the issues and challenges of sustainable development (Perks 2007). As seen in this paper, the engineering education community is now at a critical juncture. There has been a significant level of *grassroots* activities but little embedded sustainability structure or organisation within curricula design over the years since the inception of the UN Sustainable Education for meeting the goals in 1997.

The next step will be for university-level engineering schools to think more critically about what should or should not be included in a curriculum into which sustainable engineering has been incorporated and how this should be achieved. The path forward will require the evolution of a set of both tacit and explicit knowledge gain standards, as stated below. As put forward above, the 1997 report of the Joint Conference on Engineering Education and Training for Sustainable Development in Paris called for sustainability to be "integrated into engineering education, at all levels from foundation courses to ongoing projects and research" and for engineering organisations to "adopt accreditation policies that require the integration of sustainability in engineering teaching". This paper and its research have set out to demonstrate how this responsibility could be ingrained right from the start of learning to become an engineer.

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FIRST-GENERATION ENGINEERING STUDENTS' IDENTITY DEVELOPMENT: EARLY FORAYS INTO THE WORKPLACE

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ABSTRACT

In the context of global shortages of engineering professionals, research into factors that impact on training and retention of qualified engineers is important – this includes first-generation engineering students, a largely under-researched group of students. Research has shown that an elaborated, well-developed engineering identity is important for the retention of both engineering students at university, and for engineers in practice. Professional identities are fluid, emerging and develop over the lifetime of the professional. However, we still know little about the nature of a professional engineering identity, and how it develops.

Drawing on insights from the philosophy of science, I make an argument for a heuristic that allows for the analysis of data on engineering identity: professional identity is marked by epistemic fluency, a process of ontological becoming and axiological capacity. The paper reports on a set of interviews of new engineering professionals as they transition into their first few months in practice. The work is part a longitudinal study of first-generation engineers.

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The study shows that the workplace environment expands the emerging identities the new engineers bring into their first jobs. The analytical framework allows the researcher to tease out aspects of the developing professional identity.

The study not only adds to conversations about the development of engineering identity in the transition into the workplace using the proposed analytical concepts, but also has implications for curriculum.

1 INTRODUCTION

In 2015 the United Nations adopted the 17 integrated Sustainable Development Goals in an effort to end global poverty and ensure that all people are able to live with dignity in peace and prosperity by 2030. There can be little doubt that engineering professionals have important roles to play as the global community strives towards these ambitious goals.

We also know that there is an acute shortage of engineering professionals in both developing and developed economies around the world. Understanding factors that impact on the recruitment, training and retention of qualified professionals in the engineering field is therefore an important objective.

Research has shown that the development of a professional identity is important for both the retention of engineering students in their field of study, and for the persistence of engineers in the profession.

In many countries first-generation students form an important part of the intake into higher education in general, and engineering studies in particular (in the longitudinal study at a prominent South African university that this paper draws on, around a third of the first-year students into the engineering programmes were the first in their immediate families enter university). These students face various challenges over and above the typical transition issues that all first-year students negotiate as they enter higher education: the absence of role models in immediate family, grappling to make sense of oft-tacit expectations of what is valued in higher education, and, in many cases, facing difficulties of multiple intersecting socio-economic issues and schooling that has left them under-prepared for engineering studies.

1.1 What is a professional identity?

In a wide-ranging review article looking at research on engineering identity, Morelock characterises engineering as an "ambiguous profession" (p.1240), obfuscating attempts to define an engineering identity and what it means for students or individual practitioners to identify with the profession. What is clear from the literature, is that any professional identity is complex and contested. It is also always provisional, fluid, temporal and evolves over the lifetime of the professional. Because of the difficulty to define what is meant by a professional identity, a pragmatic starting place is perhaps simply to describe it as the perception of the self in relation to the profession.

One of the most obvious aspects of what we call professionals (such as engineers, doctors, lawyers, teachers, etc), is the expert knowledge associated with practitioners in the professions. Here, in the context of engineering, it refers to expert technical knowledge and skills. In addition, there are also values and dispositions associated with professions.

The purpose of this paper is to explore the nature of an early professional engineering identity that engineers start to forge as they enter the workplace. In the next section I propose a conceptual framework as a heuristic analytical tool. The context of the study is a seven-year longitudinal study of first-generation engineering students journeys through their studies and into their early careers.

1.2 A conceptual argument for an analytical framework

Peter Deane (2018) argues for the inclusion of philosophical insights such as epistemology, ontology and axiology to extend understanding in interdisciplinary research (such as education research). In this paper I explore these ideas, attempting to find a productive analytical lens to think about professional identity.

One of the marks of the professional, is expert knowledge in a particular disciplinary area. In the case of engineering, professional mastery of disciplinary knowledge is a central part of the engineering identity. Scholars who look at professional knowledge, go further – they refer to a *fluency* in the use of expertise (see the work done by Winch (2014)), which includes the need to wield expertise in making judgements and decisions about action. Markauskaite & Goodyear (2016) use the phrase “epistemic fluency” that they link to taking action, which they call “knowledgeable action” and “actionable knowledge” in the context of the professions.

At its deepest level, identity is about a sense of being, of becoming. There are therefore profound ontological aspects to the development of a professional identity – Downey & Lucena (2004) call the identity politics of engineering “ontological work” (p. 400). When we think about professional (engineering) identity development, it can therefore be argued that being recognised as a certain kind of person, here, an engineer, is crucial to identity development. Ron Barnett has written about the link between ontology and epistemology: in a book on the purposes of higher education, Barnett (2009) talks about the transforming power of encounters with knowledge. He makes a distinction between ‘knowledge’ and ‘knowing’, which involves an internalising of knowledge, resonating with the notion of epistemic fluency.

Axiology is a rather neglected aspect of the philosophy of science & engineering that has bearing on a professional identity (see the argument by Patterson and Williams (1998) for axiology to be included in considerations around the nature of science in natural resource management). Axiology refers to what is called value theory in philosophy. Here it recognises that engineering is not a neutral activity, but that it is inherently normative. It refers to the necessity in engineering to make values-based calls about the fitness-for-purpose of a proposed solution to a problem, and the requirement to weigh competing, and possibly conflicting, demands and needs and make professional values-based decisions – what Loui (2005) calls, “a capacious sense… [of] stewardship for society” (p.383). Another example is the concept of sustainability, in its broadest sense, that addresses the complex tensions between human aspirations for a better life and the constraints of limited resources. It speaks to the potential difference between the well-being of future and present generations.

In this paper I therefore propose a three-part heuristic or cognitive tool for considering the nature of professional identity: epistemic fluency, ontological belonging, and axiological capacity.

In the rest of this paper, I look at small set of interviews with first-generation engineers, conducted in the first few months of their entry into the workplace, and draw on the philosophical heuristic to analyse responses.

2 METHODOLOGY

The results described in this paper are part of an ongoing longitudinal study of 16 first-generation engineering students at a prominent South African university. The study is in its fifth year, and results from various stages of the project have been reported on the over the past few years. Nine students who started their undergraduate studies five years ago, graduated at the end of 2022, two were academically excluded, and five have not yet completed their studies. Of the nine graduates, one declined further participation, one went on to post-graduate studies and seven are now entering the job market. They are at an early stage in their careers (the interviews took place four months into the start of their career paths). Using qualitative data collection, semi-structured interviews of wide-ranging scope were conducted, following the various threads of interest in the larger project (identity formation, social expectations, familial relations, networking, etc.). Interviews were transcribed and anonymised, and coded according to the heuristic, using qualitative software. The data analysis draws on the heuristic developed from the philosophy of science/engineering, interpreting responses to interview questions in terms of epistemic fluency, ontological belonging/becoming and axiological capacity. In the interest of exploring the rich qualitative data in some depth, in this paper I report on aspects of the development of an emerging professional (engineering) identity of just three of the participants, purposefully selected to present variety in the employment fields students entered: software development, mining and renewable energy consulting.

There are limitations on the study in terms of the small sample size, the specific context, and the early stage of career development. However, the purpose of qualitative studies is to provide ideographic knowledge rather than generalisations – here, an understanding of the specific context of early career first-generation students provides us with a baseline study against which more traditional pathways into the development of an engineering identity can fruitfully be explored.

3 RESULTS AND DISCUSSION

In this section I discuss the identity development of the new engineers in terms of the heuristic proposed earlier, with illustrative quotes from the interviews.

3.1 Epistemic fluency

As these early-career professionals talk about their experiences in their new workplaces, they attempt to link their technical knowledge to the needs of the workplace. They feel some confidence in their training, but transitioning to the workplace environment is often still bewildering. Jerome describes how he is "shadowing other engineers to see how stuff gets done in the field" and adjusting to working a fixed workday: "it's really different to what… I expected… the most challenging thing is just getting used to the structure of working a nine to five as opposed to the loose… structure of studying".

What is quite striking about the comments made, is that the new engineers often feel most unsure about what engineering educators might call the "soft" (social) skills and knowledge. Technical report-writing looms large for Kholo, and he acknowledges that it is an area where he needs to grow: "I'm not really strong on that side because my English side also is not that strong. It's not my first language…" In addition, he finds that his tendency to “doing things on my own” (which stood him in good stead during his studies), must be tempered with working as a team member. Jerome talks about the heavy responsibility he feels for doing work that his teammates depend on: “… some people are relying on you to get your work done by the end of the day so they can use it tomorrow… I feel like it presses you to really think about what you're doing and to really like make sure that you're doing your job well”. Jerome feels pressure to succeed: “At the end of the day… especially since I'm… trying to build myself up, if I make mistakes… I can… limit my opportunities in the future”. Jerome also sees the need for project management skills, and he invests time in the online space to learn more about what he perceives to be a gap in his training.

Even so, Matteo warns that it is not possible for university engineering training to completely prepare students for the demands of the workplace: a “company infrastructure thing... it's … not something that someone at the university could prepare for, because every company… [is] different”. What is needed, is a flexibility which he confidently claims on the basis of his university engineering education: “I feel like the engineering degree like has helped me… pick up things faster so you know… you don't need to ask… what the process is because you already identified [where to start]”. Matteo, perhaps most clearly, displays the inception of a budding epistemic fluency as he describes his interaction with stakeholders which is part of a skill he has to develop to deliver on developing software solutions to identified problems. The different kinds of epistemic demands require him to translate vague user requirements into technical requirements: “someone says… we want things to run faster… or if you want this process to be different, it's like, well, how do you want it to be different? … you need to quantify it a bit, you know … the requesting team has to break it down more. And then we… break down their requirement into… more understandable requirements for our back end and front end”. What he describes comes close to what Markauskaite and Goodyear call “actionable knowledge”. Furthermore, Matteo recognises that while there may be short-cuts, and off-the-shelf work-arounds, the deep disciplinary knowledge from his technical engineering science training provides a framing for his approach to problems: “… if you want to improve something, you need to understand how it actually works“.

3.2 Ontological becoming

A professional identity is fundamentally about a perception of the self in relation to the profession. In the entry-level engineering roles in which our study participants find themselves, some struggle to find a sense of belonging. Jerome finds it hard to relate to his (older) work colleagues who fit a more traditional role: “I'm not sure of what an engineer looks like, and to be honest… I look at people at my work and… I can't really relate to them… I don't know if it's the generational differences… how they… specifically, how they dress and how they act”. However, his feeling of disconnectedness is linked to the specific job, not to his identity as an engineer. He holds on to quite a clear picture of himself in a different working environment – this represents intrinsic motivation for future change: “I really want to work somewhere in the design space where I can feel like I have more space or freedom, to… express my creativity and where I … [can] just push the boundary of … electronics or robotics a bit”. Jerome struggles with the routine aspects of his current position: “[there are] specific recipes… already in place, and if you follow them, you'll get the work done… It's very boring”. He expresses a need for “something where… I can sit down for two to three hours and then just think about it and try and solve this problem… I find that really rewarding where you come up with this idea, you grapple with it for a bit, and then here you see the thing – it works."

Kholo is also uncertain about a long-term commitment to the company where he is starting out. While he appreciates their support in starting the process of gaining status as a professional engineer, he is ambivalent about his opportunities at the company and the potential for him to meet extrinsic personal goals that focus on material needs: "My responsibilities might change… maybe I want to get married… I'm trying to support my family and build a house for my mother… I need something that can make things happen quicker… like pay me more".
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Matteo, on the other hand, has a strong sense of belonging in his place of work. He speaks about doing "what I enjoy and… what keeps me… interested and entertained at in this role". Matteo's sense of belonging stems from his supportive line manager: "…if I come up with an idea, she's like... Let's set up a meeting with these people and get it going". He has a confident sense of his place in the organisation: "Look, it's still… very early in my career and… I would… like to stay in the industry because there is a lot of opportunity… I want to be in technology, I want to… push for new ideas to bring into… the banking world". His motivation for staying in his role is intrinsic: "I've spoken to my manager about the path that I want… if I'm not given the opportunity for that, then I would probably move. But… if I'm afforded with the opportunity of growing within the company, then I don't need to go anywhere else."

It is interesting to see how the different kinds of knowledge and skills implicated in epistemic fluency also speaks deeply to issues of belonging and becoming (ontological concerns)—some experience these as constraints, while other participants find epistemic fluency enables a stronger sense of belonging. For Kholo his perceived struggle with report-writing in his new job reminds him of how his lower mark on his Final Year Project report at university cost him a first-class honours pass in his undergraduate degree "… it was so close to getting there and I feel if I … [had done] well in my… report, [I would have received] a distinction in my average." At this stage of his career the report-writing presents a shortcoming and forms part of the way in which he sees himself in relation to his work. Jerome faces similar ontological concerns in his need to work more collaboratively in a team – he speaks of his "personality… limiting" him, and how he has had to learn to approach colleagues with questions. He can see change in himself, necessitated by the demands of working with others. Matteo's ability to fluently negotiate his role to translate user demands into technical requirements that his team can respond to, gives him confidence to "kind of feel like you [are] always… contributing".

3.3 Axiological capacity

In this paper I argue that the development of an axiological capacity is an integral aspect of the development of a professional identity. Participants in the study voice this in different ways. Matteo sees links between the notion of sustainability (typically "associated with climate and the environment") in more encompassing ways to include the question, "is what you're investing in, … whether it's yourself, … or whatever, is it going to improve processes in future that will lead to a more productive, healthier, more efficient... kind of reward at the end?" For him this includes ideas around equity: "… in the sense where it's rewarding for everyone, not just for select few, for example". He argues that improving efficiency cannot be considered in isolation and has to be held in tension with potential undesirable consequences: there are constantly questions about, “can we make it more efficient… what are the impacts and how can we reduce… if there happens to be, you know, some sort of … negative impact”.

Kholo describes sustainability as “using resources we have now so that future generations can also benefit from them. I feel like engineers are very focused that way”. Kholo sees his company making value decisions based on the intersection between ethics, environmental concerns, societal responsiveness, and economic constraints: “engineering, ethics and all that... overlapping engineering and the environment, overlapping engineering and society, overlapping engineering and economics”.

For Jerome his engineering studies sensitised him: “our control and automation course... they spoke… about the processes that goes on there and how whenever you design, a process plant… you need to take into account that… there's going to be limited amount of [resources].” Jerome finds it interesting to see how these value-based notions manifest in the practices of the mining company he works for: “… they are really trying to minimize their environmental footprint and so they do a lot of rehabilitation work.” Jerome explains that he has become more aware of making value decisions in his new role: “I've really seen it over the past 2-3 months… in my work, where I'm kind of forced to really think about how my work is affecting not only the immediate surrounding area or resources that's available, but then also how? How long can this specific sensor last… how often does it need to be replaced and where does the waste go once it's taken off? All that because… on site we have a very limited amount of space where we can [dispose of] waste and we're trying to minimize that… over the lifespan of the mine…”

3.4 First-generation students – early engineering identity

First-generation students start their university training in many ways with less information on what engineering entails because of the absence of role models, and less exposure to networks that can inform and support. To qualify for acceptance into competitive programmes in top universities, these students develop coping mechanisms to compensate for the absence of support structures --- their journeys into higher education are often marked by lonely independence and having to forge their own way. Kholo describes what it is like “coming from a… school where resources are limited. We literally [only] had one teacher teaching [all] the physics and chemistry [in the school]”. His teacher was not coping with the content and “I needed to go through the textbook on my own and … trying to correct [the teaching] in class at times”. This ability to work by themselves served them during their years of study, but in the workplace they now need to learn skills of working with others. Jerome explains, “It's very much team-based and you have to… draw from the expertise of other people to get the job done.” New engineers need to recognize and grow in their ability to contribute meaningfully a common objective.

While acknowledging that ontology, epistemology and axiology do not exist as separate concepts in a study such as the one undertaken here, the distinctions become useful for analytical purposes as a heuristic.

4 CONCLUSION

In this paper I explored the nature of the engineering identities being developed by some first-generation engineers as they enter the workplace after graduation. The workplace environment serves to elaborate the nascent identities that engineering students bring from university. The study shows that the transition makes new demands on the young professionals who must resolve the way in which the skills and knowledge they bring with them, translate into the workplace.

This qualitative study involved first-generation engineers. Study participants had less they could rely on in the transition into and through engineering studies (Hunt et al, 2018). They developed resilience and determination as coping skills to make their independent way. However, at the same time, the very independence and self-reliance that stood them in good stead in their studies, now must be moderated to accommodate the workplace priority of working in teams to solve problems.

The analytical framework of epistemic fluency, ontological becoming and axiological capacity provides a useful way to conceptualise professional identity in general, and engineering identity in particular. The new engineers start their first careers with technical knowledge and skills, but the workplace demands a flexibility and fluency that integrates different kinds of knowledge and action. For some their first job is not an ideal fit and they have to use the experience to clarify own priorities and the way they see themselves. For others, their first job fits hand-in-glove, and the interviews revealed a strong sense of becoming and belonging. New engineers grapple with axiological considerations in their new jobs: relating competing demands that require value judgements, juggling regulatory requirements, personal values and company ethos take them beyond superficial definitions of efficiency and sustainability.

The study contributes to the literature on the development of an engineering identity (Morelock, 2017), and the longitudinal nature of the project potentially allows for a more coherent view of the process. The insights arrived at can fruitfully translate into a framework for larger more comprehensive study of thinking about identity development. There are several avenues that could fruitfully be explored in the near future. Similar to the disruption all new technologies bring, the proliferation of artificial intelligence and use in the workplace push boundaries and raise new questions around identity: what does “knowing” and “knowledge” look like in this age? What does epistemic fluency become? What does “belonging” include in this age of chat bots? What changes will be introduced in the axiological space? Where do we take our questions about what should be valued, what matters, of what it means to have an engineering identity? All these questions have implications for what it means to be and thrive as an engineer.

The findings potentially have implications for engineering education: new engineers report less confidence in their ability to negotiate the more social aspects of the engineering workplace: making meaningful contributions to work teams, writing the technical reports that are needed, and managing real-life projects. Planners of engineering curricula would do well to keep in mind that these sometimes-neglected parts of the curriculum become crucial as new engineers negotiate entry into the workplace and formulate new ways to relate to their profession.

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A CRAZY LITTLE THING CALLED SUSTAINABILITY

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ABSTRACT

Achieving the 17 Sustainable Development Goals (SDGs) set by the United Nations (UN) in 2015 requires global collaboration between different stakeholders. Industry, and in particular engineers who shape industrial developments, have a special role to play as they are confronted with the responsibility to holistically reflect sustainability in industrial processes. This means that, in addition to the technical specifications, engineers must also question the effects of their own actions on an ecological, economic and social level in order to ensure sustainable action and contribute to the achievement of the SDGs. However, this requires competencies that enable engineers to apply all three pillars of sustainability to their own field of activity and to understand the global impact of industrial processes. In this context, it is relevant to understand how industry already reflects sustainability and to identify competences needed for sustainable development.

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This article therefore first presents an explorative qualitative study that provides information on the extent to which sustainability is addressed by engineers in central management positions in German industry (focus on manufacturing sector). Results show a need for teaching concepts in which future engineers increasingly deal with sustainability concepts and the global impact of their own actions. The survey indicates that the social pillar of sustainability, in particular, is often left out of the equation and, consequently, is rarely considered in industrial sustainability efforts. Based on these findings, an interactive teaching concept is presented that uses the design thinking approach to sensitize future engineers to all three pillars of sustainability.

1 INTRODUCTION

Climate change and its far-reaching consequences on the global population require a stronger focus on sustainability when it comes to educating future generations. The need for intergenerational reflection on one's own actions is demonstrated not least by the United Nations Brundtland Commission, which defined one of the most cited definitions of sustainability: "[…] meeting the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations, 1987, p.15, [1]). This definition results in a (social) responsibility of today's generation, which extends to the private spheres of life as well as to the professional scope. In order to reflect on sustainability in a holistic way, the three pillars of sustainability - economy, ecology, society - represent a guiding concept helping to understand the complexity of sustainability questions (e.g., [2], [3]). Despite the different scientific discourses on the order of the three pillars [4], a strong or weak understanding of sustainability [5] or a required focus on the ecological pillar [6], scientists and practitioners agree that a reflection of all three pillars is necessary to act in a holistic manner.

As sustainable action is significantly influenced by the technologies available and used, especially engineers and the technology industries in which they operate are decisive factors having an impact on how sustainable the global society can be [7]. For example, with their strategic direction if development processes focus also on energy-saving technologies and if designed products are inclusive and thus can be used and afforded by a broad target group, technology industries have an impact on sustainable actions. This is also supported by the association of German engineers (VDI), as the largest technical and scientific association in Germany, stating that natural science and technology are essential factors in shaping the present and the future, which results in a special responsibility of engineers [8]. In addition, engineering-based management in particular has an influence on entrepreneurial orientation and the consideration of sustainability in product development [9].

To enable future generations of engineers to reflect sustainability in an holistic way and to make sustainability a part of management, teaching approaches are needed that ensure a detailed examination of the concept of sustainability and the transfer of the three pillars of sustainability to one's own field of action. In order to be able to develop teaching concepts that are linked to entrepreneurial reality, it is first necessary to gain an insight into the extent to which sustainability is already reflected and practiced in the management of engineering industries. This makes it possible to identify needs that must be addressed in engineering education in order to create a holistic understanding of sustainability.

Therefore, in a first step a study is presented that examines the perception of sustainability in the context of engineering enterprises. The study was conducted under the heading of digital transformation and the investigation of corporate strategies, change approaches and organizational processes. The underlying theory was that a targeted survey of the respective understanding of sustainability tends to reveal socially desirable perspectives. It was therefore decided to analyze sustainability in the context of digital transformation, since digitization projects are already understood and broadly discussed in the context of sustainability [10, 11]. This allows conclusions to be drawn about the extent to which sustainability is already reflected in the management of the respective industry and what contribution teaching concepts must make in order to tie in with this actual state.

2 METHODOLOGY

In this chapter, the target group of the study is outlined and the procedure within the framework of the study is explained.

2.1 Sample & Data Collection

To ensure an inclusion of different engineering fields, study participants were recruited from the Industrial Advisory Board (IAB) of the Cluster of Excellence Internet of Production (IoP) at RWTH Aachen University [12]. The members of the Industrial Advisory Board are distinguished by their many years of experience in the German industry and their focus on engineering or information technology topics. In addition, the members come from a wide variety of sectors (e.g. textile industry, automotive industry, energy industry) and thus represent a broad engineering experience. The participants can be assigned to middle to upper management, so that it is possible to classify the sustainability activities for the respective area.

38 participants of the Industrial Advisory Board were contacted in total. 15 additional contacts were made via the Institut für Textiltechnik (ITA) of RWTH Aachen University, to ensure the inclusion of managers of textile industry. The special characteristic of the textile industry lies in the many years of dealing with sustainability, especially in the textile production context [e.g. 13]. This results in a total of 53 people invited to the qualitative survey. 31 interviews were conducted, which results in a response rate of 58.5 %. Regarding gender distribution, 30 participants identified themselves as male, and one as female. Participants were members of the upper management level, which ensures an overview over company strategies, strategical directions and thematic priorities in the respective organization.

Regarding the interview language, 28 interviews were conducted in German and three in English. 30 interviews took place via an online conference tool, one interview was conducted in presence at the organizations headquarter. All interviews were recorded and transcribed using the computer-assisted qualitative data and text analysis software MAXQDA. The average duration of the interviews was 50 minutes.

2.2 Data Analysis

In order to investigate to what extent sustainability is addressed and reflected by the interview partners from German industry, a qualitative approach was chosen to enable a deeper analysis of perceptions and application approaches. Against the background of the approach and the intention of not specifically asking for concrete sustainability approaches in order to avoid biases, an analysis instrument is needed which, through structured process steps, allows an in-depth analysis of the described sustainability perception in one's own field of activity. The analysis method chosen was the qualitative content analysis according to Mayring (2015) [14]. The content analysis is a structured analysis method and offers at the same time freedom '[…] to adapt the concrete object, the material and constructed to address the specific question.' (Mayring 2015, p.51, [14]). By analyzing content in a structured way, it is also possible to summarize qualitative data statistically.

3 RESULTS

Building on the study described in chapter two, the study results are summarized and discussed below.

3.1 Findings and Discussion

Five out of the 31 interviewees (16.1 %) addressed sustainability without being specifically asked about it. In doing so, all five interview partners reflected sustainability in the context of the company's field of activity and thus associated with the individual professional focus. Consequently, the field of activity of material production (Interview No. 12), classical mechanical engineering (No. 14, 24, 25), and the energy industry (No. 22) are represented. Sustainability was associated with the topics production processes (No. 12, 24), the Co2 footprint and the energy transition (No. 12, 14, 22, 25) as well as the general need for energy efficiency (No. 12, 24, 25, 22), which were explicitly mentioned. The topics mentioned indicate that the focus of consideration is on the ecological pillar and also on the economic pillar. Only two of the interview partners addressed the social dimension of sustainability and reflected people as consumers who are interested in sustainable products, as employees in the context of individual reflection on the necessity of business trips (No. 12) and as future generations employees and their role in climate change (e.g., *'[…] a person who goes on the road with Fridays for Future and tells me 'How can you work for this store*?*' – No. 22, * In this context, *store* means a disrespectful designation of the respective organization).

Transferring the results to United Nations (UN) sustainable development goals (SDGs), this picture is confirmed. Most of the topics addressed are in the context of goal 7 – Affordable and Clean Energy and goal 9 – Industry, Innovation and Infrastructure. A deeper analysis of the associations with sustainability shows that sustainability seems be viewed rather superficially (e.g., '*But productivity will be needed, for example, to meet future sustainability requirements, which are becoming increasingly important*' – No. 24).

In summary, the results indicate that in the context of engineering business, the ecological and economic pillars of sustainability are mainly addressed. It is striking that the ecological issues are topics that are more strongly addressed in the political discourse and thus lead to new framework conditions and economic effects for the companies. In the absence of corresponding public discourse on the social perspective, it is therefore not surprising that the social pillar appears as a marginal topic. However, this is accompanied by the assumption that there is still no awareness of the triad of sustainability pillars and thus no awareness of the need for interrelations between ecology, economy and social issues.

3.2 Limitations

In view of the framework conditions of the survey and the methodology, there are limitations against which the results must be reflected. The survey was conducted during peak phase of COVID-19 pandemie. The resulting industrial situation had a significant influence on the interviewees. At this point in time, geopolitical developments that occurred in 2022 did not yet have an influence on the response behavior in the context of sustainability. In addition, the investigation of sustainability perspectives was a side analysis basing on the investigation of digital transformation. This means that interviewees weren't ask directly for reflecting sustainability, for preventing socially desired response behaviour. Esser (1991) argues that within the framework of rational choice theory, respondent behavior can be regarded as a special case of a general theory of situation-oriented action [15]. It is argued that respondents' answering behavior is not determined in advance by fixed orientations and attitudes, but emerges within the situation of the interview in mutual influence with the interviewer by comparing different, alternative possible answering options [16]. Consequently, the chosen approach can be defined as explorative.

Despite the limitations resulting from the framework conditions there are also constrains resulting from the qualitative method. Due to the high (time) effort of qualitative studies and especially expert interviews, the number of the conducted interviews cannot be defined as representative in a statistical sense. This results in a limited overview over the reflection of sustainability in engineering branches.

However, the presented results should be seen as a starting point for further investigating the prevailing perspective on sustainability in engineering branches and, furthermore, identifiying areas of activities for the respective companies in the sustainability context.

4 TRANSFER INTO HIGHER EDUCATION

Study results indicate a need to integrate the topic of sustainability into engineering study programms and to tie sustainability to the practical context. This means that teaching concepts must ensure that all three pillars of sustainability are addressed, critically discussed and applied to the engineering field. In the following, a teaching concept is presented that provides an interdisciplinary and transdisciplinary conceptual framework and is based on the three pillars of sustainability. The so-called sustainability challenge was developed to provide an interdisciplinary and transdisciplinary perspective on all three pillars of sustainability in engineering. In order to achieve this, importance is initially attached to heterogeneous teams (with regard to cultural background, specialist background and gender) to achive the integration of different perspectives and to create an interdisciplinary working environment, as is also prevalent in industry. In doing so, the course concept is based on the key processes, learning environments and competencies identified by the UNESCO expert review of processes and learning for Education for Sustainable Development (ESD) [17].

4.1 Course concept

The course consists of both on-campus and online elements. The course begins with an online kick-off event during which the students get to know each other, receive a theoretical introduction to sustainability concepts [e.g., 4, 5, 6] and learn about the topic of the sustainability challenge (see fig. 1). The sustainability challenge is characterized by being thematically broad in order to enable a transfer to different contexts and to different people and cultures. For example, an engineering perspective on floods can be reflected against the background of all three pillars. After the online kick-off, three block courses follow, focusing on the triad of the three pillars of sustainability. The resulting block format allows a low level of collision with term-accompanying events which aims to make it possible for students not only from different faculties but also from different universities to participate in the challenge.

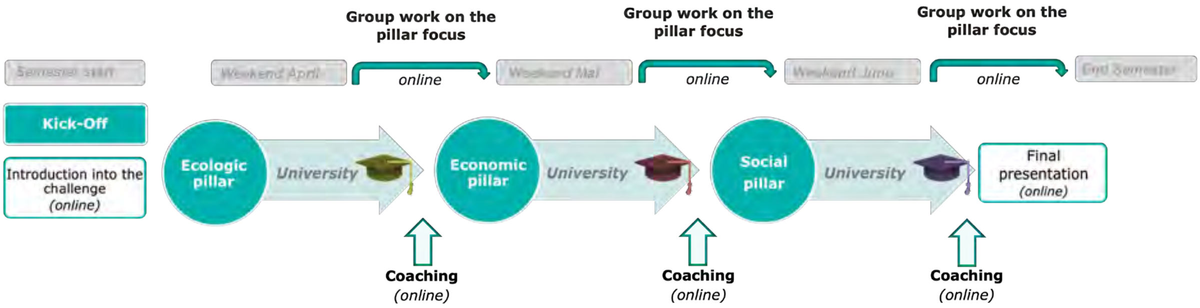

Fig. 1. Course Concept – Sustainability Challenge

The diverse student teams are accompanied in their work on the respective pillar with the help of methods that provide a transdisciplinary perspective on scientific topics. For example, design thinking can be used as a methodological approach when addressing the social pillar of sustainability. Design thinking is a five-step process that focuses on identifying the needs of potential users. In order to be able to develop solutions and products that meet these needs, the first step is to take a comprehensive look at the user's perspectives. The social pillar of sustainability also requires an in-depth analysis of user perspectives in order to develop solutions that are, for example, socially equitable, reflect diverse needs, are generally accessible, have a high acceptance and address the realities of life of the identified target group. In doing so, an inter- and transdisciplinary approach is ensured as both disciplinary and institutional boundaries are crossed with the help of population surveys, and the disciplinary mix of groups which strives to integrate different disciplinary ways of thinking. [for more information see 18]

Between the blocks, the students work out the solution to the challenge against the background of the respective pillar focus. The focus on single pillars is deliberately chosen, as the students are supposed to deal in depth with the framework of the respective pillar. It is well known that a separation of the pillars is not possible in reality and that there is an interdependency between the three pillars of sustainability. Students are therefore encouraged to consider this aspect in their final presentation. To support them in this step, online coaching sessions are held between the block courses to clarify prevailing questions and to support the students in their teamwork. Especially in the case of heterogeneous teams, there is a need for active guidance and support through coordinating measures. Due to the diverse perspectives, there is a higher potential for conflicts, more discussions take place and negotiation processes take more time [19].

After the students have dealt with the three pillars, the final presentation of the results follows. The results represent a summary of the knowledge gained and solution approaches developed in the three course blocks.

It must be taken into account that corresponding format is accompanied by a limitation of the number of participants. Consequently, the presented concept is designed for a maximum group size of 30 people. However, it is possible to scale the challenge concept with more collaborative partners so that a larger number of students can participate.

5 SUMMARY AND ACKNOWLEDGMENTS

In conclusion, a concept is presented ensuring the reflection of all three pillars of sustainability. The concept was motivated by a qualitative study conducted in industry, which indicates the need to teach future engineers all three pillars of sustainability using practice-oriented cases. The study has shown that it is necessary to relate sustainability to engineering topics in order to enable engineering students to transfer sustainability concepts into their future field of activity.

The concept can be transferred to different contexts. For example, three faculties of a university can cooperate or the three pillars can be viewed more internationally through the cooperation of several universities. In this context, it should be taken into account that cross-organizational cooperations require close interdisciplinary collaboration and a coordination of the applied (transdisciplinary) teaching approaches (e.g., design thinking) that enable active engagement with society.

The presented concept represents a first step to ensure that sustainability is taken into account in a more sustainable way in the engineering business context. Only if we succeed in making sustainability an inherent part of engineering education we can ensure that ecology, economy and social perspectives are taken into account in the technology of the future and that technological development can contribute to achiving the 17 sustainable development goals.

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Addressing long-term challenges in energy for sustainable futures by applying Moonshot Thinking

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ABSTRACT

The rapid and exponential changes in our world require the education of engineers who can develop solutions to future and long-term challenges such as climate change. Exploration and innovation methodologies such as Futures Thinking and Moonshot Thinking have the potential to equip engineering students with useful tools and skills to build sustainable futures. To this end, the InnoEnergy MSc Energy for Smart Cities programme at BarcelonaTech (UPC) has developed a challenge-based learning (CBL) course that applies moonshot thinking to tackle major energy problems. This paper presents the methodology refined over three years of implementing the CBL course with second-year Masters's students in Energy Engineering. The course begins by constructing a narrative working future using exploratory tools from the Futures Thinking methodology. Breakthrough technologies are introduced, and their disruptive potential is analysed. Students then define a long-term sustainability and energy problem and use various ideation methodologies to develop a solution. Using technologies such as 3D printing, artificial intelligence and open-source electronic prototyping platforms such as Arduino, they build a minimum viable product (MVP) and develop a business model. Finally, using an agile approach, students must design future iterations and analyse the potential exploitation of their solution. This subject equips students with the necessary skills to address complex energy and sustainability challenges, and the course has proven effective in preparing students to apply their knowledge in practical, real-world settings.

1 INTRODUCTION

How do we train students for jobs that have not yet been created, to use technologies that have not yet been invented, or to solve problems that we cannot yet imagine? These are some of the concerns raised by international organisations such as the Organisation for Economic Co-operation and Development (OECD) [1] when examining the future of education. Others, such as UNESCO's International Commission on the Future of Education [2], point out that the key is to advocate curricula that develop creativity, engagement and a broad range of skills through community-engaged, project-based pedagogies.

In 2020, the Moonshot pilot was created by the Universitat Politècnica de Catalunya-Barcelona Tech (UPC) as part of the MSc Energy for Smart Cities programme, in collaboration with Fab Lab Barcelona and with the support of the European EIT organisation InnoEnergy, as a response to these new educational challenges.

The moonshot took humankind into space and allowed us to leave a footprint on the moon. Years later, the concept of moonshot thinking has evolved into a way of tackling big challenges, including climate change, by coming up with unconventional ideas and using disruptive technologies to find solutions. The key principle of the course is that it is often easier to make something 10x better through radical change than it is to make it 10% better through incremental improvement. Students must validate their most innovative ideas under tight deadlines and high targets to achieve this goal. They are required to test prototypes with the intention of failing and then learn from that failure to make the next prototype much better while maintaining an ethical focus on the environmental and social impact of their ideas and projects.

2 THE MOONSHOT THINKING PROGRAM AT BARCELONATECH-UPC

The main objective of this course is for the student to go through the process of moonshot thinking and to learn about the different stages of this methodology. Students are expected to learn about the methodology, develop key skills in applying the methodology, and become autonomous decision-makers.

This course has been implemented as a pilot project exclusively for MSc Innoenergy students during the three years from 2020 to 2023. It is a 15 ECTS semester-based course and consists of blocks, as shown in Fig. 1.

The course is divided into eight blocks, as shown in Figure 1. The grey blocks represent the general topics (Introduction and Presentation). The blue blocks cover the brain activities (Futures Thinking, Problem Analysis, Ideation and Solution Development, and Exploitation and Business Development), while the green blocks address the hands-on activities (TAUM and Sensors and Product Prototyping). The course starts with a block on introducing the methodology of moonshot thinking and its basic philosophy. Examples will be given, and references to existing projects (including those in the energy sector) will be discussed.

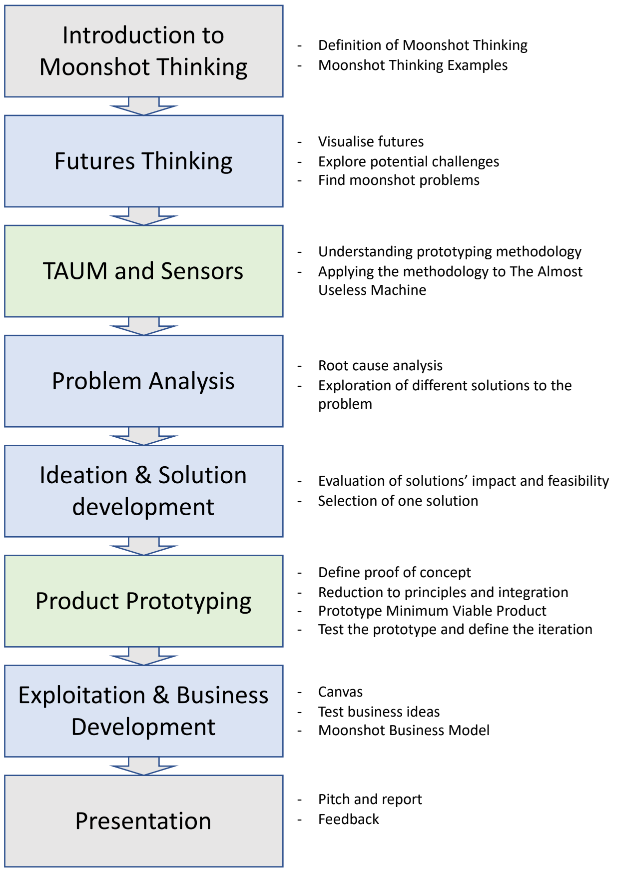

Figure 1: Overall methodology at the Innoenergy UPC Moonshot Thinking Course.

The brain activities start with *Futures Thinking* block. Concepts such as different futures, weak signals, moonshots in the electricity grid, the Sustainable Development Goals, exponential technologies, megatrends and activities such as describing the future or asking "how could we..." questions were carried out. This phase provides students with valuable insights into the major future issues facing the energy sector, particularly in the decade 2030 to 2040. Students can choose a specific topic to work on in groups of 2 to 4 students.

The hands-on activities start with an introductory block on rapid prototyping technologies, through a practical session on the prototyping methodology, but not applied to the specific idea (TAUM-The Almost Useless Machine). The outcome of this block is solely to provide the student with knowledge and skills in rapid prototyping technology and its practical implementation. The Problem Analysis block devotes activities to the analysis of selected scenarios from the Futures Thinking, the identification of problems, the analysis of the root cause of the problem and the exploration of different solutions to the problem. The next block is dedicated to the Ideation process, where Design Thinking methods are used to define disruptive ideas without putting the students' creativity at risk. The Product Prototyping block is dedicated to prototyping a proof of concept of the specific idea from the ideation process, evaluating the design, and testing the developed prototype and iteration. The following block is related to exploitation and business development and explores the future potential of the disruptive concept and the business dimension. The outcome of this block is the ability of students to transform disruptive ideas into business opportunities using a methodical approach.

The course concludes with presenting the project to a panel, including external judges. Students present a pitch and report on the moonshot project, including the process steps. Special attention is given to the integration of different steps and future work. The course assessment is based on the deliverables, the final presentation and the student's work and impact throughout the semester. The pilot was carried out over three years with the participation of 17 students, almost evenly distributed over the three years and balanced in terms of gender.

3 FUTURES THINKING

Engineering degree programmes provide students with a comprehensive education in fundamental principles and theories, enabling them to develop the knowledge and skills necessary to apply advanced technologies and solve complex real-world problems. Most challenge-based learning (CBL) subjects in these programmes take a present-forward approach, addressing current challenges to develop robust and sustainable solutions. However, the Moonshot Project takes a reverse methodology, imagining a possible future and developing solutions backwards to the present, resulting in long-term and innovative solutions fostered by exponential technologies.

Futures thinking, or foresight, equips students with skills and resources to approach problem-solving strategically. While controlling or predicting the future is limited, conceptualising the future influences present attitudes, behaviours, and decision-making. Futures thinking ensures that breakthrough ideas pursued in Moonshot thinking are grounded in reality and have a practical path forward.

Futures thinking explores the possibilities, opportunities and risks that may arise in some years. Multiple potential scenarios exist, challenging assumptions and expanding perspectives while uncovering trends and signals that inform our understanding of how the future may unfold [3].

Alternative futures can be categorised as possible or probable based on the level of uncertainty, calling preferable futures those that align with normative value judgments. Recent developments in foresight studies have expanded this taxonomy to include plausible and preposterous futures and concepts like wild cards and black swans. Figure 2 illustrates the Plausibility Cone, which provides a framework for understanding how these different futures fit together [4, 5, 6, 7].

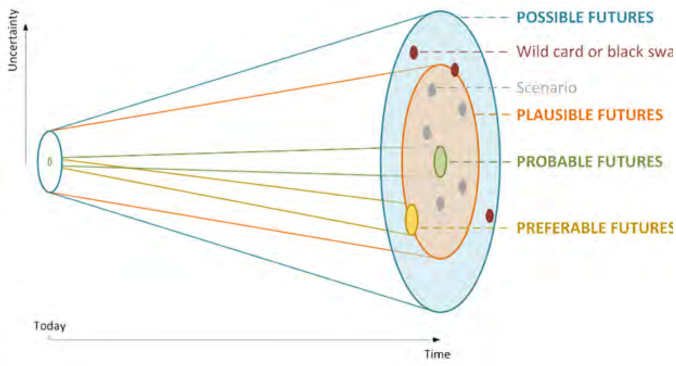

Figure 2 Futures Cone followed in the Moonshot Thinking Course.

The exploration of futures follows an inside-out approach, starting with probable futures by exploring current megatrends and past events. To analyse plausible futures, the students develop scenarios based on their understanding of how the world works. The spectrum is broadened with possible futures by introducing wild cards or black swans, seemingly improbable events with disruptive impacts. Finally, the students define their preferable future and work backwards to the present, identifying areas requiring disruptive innovation. The backcasting methodology helps align long-term visions with short-term actions, enabling the development of practical and actionable solutions. [7, 9].

The learning block incorporates resources from the Joint Research Center of the European Commission. The exploratory workshop "Working with megatrends" is conducted to explore probable futures, and the role-play simulation tool called "The Scenario Exploration System (SES)" is used to delve into plausible futures in sustainable cities. These activities enhance understanding of future energy systems and cities, fostering creative thinking and innovative problem-solving skills [9, 10].

4 IDEATION: FROM THEORY TO PRACTICE

Google X [11] is one of the organisations that has launched more disruptive projects of diverse nature in the previous years and has conceptualised the term “*Moonshot*”, consisting basically of the intersection between three concepts: (1) a huge problem in the world that affects millions or billions of people; (2) a radical, sci-fi-sounding solution that may seem impossible today; and (3) a technology breakthrough that gives us a glimmer of hope that the solution could be possible in the next 5-10 years.

The case of Henry Ford disrupting mobility, from horses to cars, illustrates the intersection: (1) the huge problem was related to the feeding of horses and the accumulation of their faeces on streets [12], (2) the radical solution was the replacement of animal traction and (3) the breakthrough technologies were the gasoline motor and the assembly line manufacturing method that allowed replicability (related to the concept of “abundance” in [13]). The etymological definition of the verb “*to disrupt*” can be defined as “*to break something into pieces*” [14]. In this example, Henry Ford disrupted “mobility” by replacing one of the elements involved in mobility:

animal traction. This innovation opened new markets and expanded the concept of mobility, such as motorbikes, trucks, aviation, etc., reshaping the entire ecosystem in a reminiscence of the concept of "*creative destruction*" [15].

On the one hand, today, the convergence and democratisation of technologies [16] make it easier for small players to develop disruptive products. On the other hand, large incumbents are more aware of the potential risks derived from disruptive innovations. Therefore, they actively search for new entrants that could challenge their dominant market position and absorb them before becoming outcompeted.

The practice of Moonshots is not straightforward. In the "Futures Thinking" sessions, the students devise a set of long-term scenarios, pointing out the direction of their project and the goals to pursue. The underlying questions of "How *to get there?*" or "How *might we…?*" aim to trigger new ideas of solutions and applications.

We surveyed students to discover their interests and ensure group alignment. Moreover, we requested that students write down their vision as a long paragraph since writing has proven to be an efficient tool for distilling and organising thoughts. Furthermore, we have scheduled a set of deliverables after the major milestones so that students find the time to document and report their progress. This way of doing this makes it easy for students to write the final report.

In this 2022-23 edition, we have dedicated more time to the ideation process, aiming that the students would develop high-potential ideas and would engage more in the project. Our expectations were met mainly but at the cost of students having limited fluency and clarity in pitching their idea to third parties. The teams came up with two topics strongly related to energy: (1) a system for CO2 capture for urban mobility, eventually linked with CO2 circularity, and (2) a power electronics box interfacing the grid users, enabling self-operation of electricity grids.

For filtering ideas, we have explored two criteria. The first one is based on the lemma "*disruptive ideas open new markets that did not exist before*". The second criterion is based on the Attractiveness Map [17], which classifies the ideas based on Challenge and Potential estimates. Moonshot ideas score as "super-high challenge" and "super-high potential".

Contrary to the traditional approaches, in Moonshot projects, students must find themselves a high-potential topic, pose the questions, ideate a solution, acquire new knowledge, build a prototype and test it. Full of uncertainty and failed experiences, this process can lead to frustration. Some of the professors' tasks consist of guiding the journey, providing tools and reflections, and keeping their goals ambitious.

After finding the most promising idea, the students do not immediately see the big picture and need some time to mature it. We request students to submit a report describing the Moonshot solution in general terms, do an initial literature review and anticipate the main components of the solutions and activities to do, trying to prioritise them, following Google's lemma: "*hardest things first*".

We encountered two profiles of students. Most of the students have a vague idea of their project and tend to need help in making their vision more concrete and specific.

The challenge for the professors is to guide the ideation process and provide tools and criteria for discarding ideas. Other students have a pre-defined and particular idea of the project, often based on their field of knowledge, without testing its innovation potential. These students can be emotionally attached to their ideas and tend to reject an evaluation of their own idea with objective criteria. The students may perceive the ideation as unnecessary and a handicap for progressing in the topic. A certain degree of detachment is needed to run an objective analysis. Hence, the challenge for professors is to enable the ideation process while playing down (not rejecting) the students' initial ideas.

5 MOONSHOT BUSINESS MODEL

We recall the concept of "*Job-To-Be-Done*" (JTBD) [18], as the ultimate need to be satisfied. We cite its definition [19]: "*JOBS-TO-BE-DONE is best defined as a perspective — a lens through which you can observe markets, customers, needs, competitors, and customer segments differently, and by doing so, make innovation far more predictable and profitable*".

In the example of Henry Ford against animal traction, the JTBD stays the same: the need for mobility "*go from A to B*". Ford's invention converged two technologies: the gasoline motor and the assembly line manufacturing method. Today, Internal Combustion Engine (ICE) cars are being disrupted by Electric Vehicles with self-driving capabilities, which happen to solve the problem of carbon emissions and car mortality with the convergence of breakthrough technologies, such as *light* batteries, sensors, computation power, etc. [20].

When practising with the students, we need to analyse their idea to unveil the JTBD, the value created and for whom it is valuable. Given the scope of energy, we practice with ongoing cases, such as EMROD, for a mid-long distance wireless transfer system [21]. This type of analysis is necessary to draft a business case. For instance, in the project of a CO2 capture device for mobility, the analysis revealed that such a device would create value for a broad range of stakeholders, such as the ICE vehicle owners (especially those more challenging to decarbonise, such as tractors or old vehicles), manufacturers, and municipalities, amongst others.

We practised the Value Creation Ecosystem [22], a useful tool for (1) identifying the relevant stakeholders and the value exchanges between them and (2) representing visually the exchanges, which helps students see the big picture. This tool is best for practising interactively with students, drawing the ecosystem together by asking them questions and letting them come up with the answers.

We also practised the popular Business Model Canvas [18], a beneficial tool to analyse existing businesses and design new ones by "*pivoting the business model*" [23]. In the previous edition of Moonshot Thinking, we observed that they were reluctant to explore changes once the students drafted the first Business Model. This time, we requested students to explore different models inspired by the 55 business model patterns by the Business Model Navigator [24, 25]. This change met our expectations: the students were later more eager to explore alternatives and imagine different ways of monetising their projects. Moreover, having a market and business idea can help students prioritising their efforts in the prototyping phase.

6 IMPLEMENTATION OF RAPID PROTOTYPING

Moonshot Thinking follows an agile approach, emphasising iteration and rapid prototyping to develop effective solutions. However, this process can take up to 10 years in a project setting. Due to time constraints in the subject, the process is condensed to six months by introducing rapid prototyping. This process, which happens within a Fab Lab environment, involves creating a proof of concept and conducting experiments to test the solution.

After receiving foundational knowledge in prototyping technologies such as CAD design, Arduino, and machine learning, the students enter the Fab Lab Barcelona. Their initial experience prototyping involves the "The Almost Useless Machines" module (TAUMs), a three-day intensive introduction to fabrication, physical computing, and the Fab Lab environment. TAUMs teach effective time and resource management during prototyping sprints. Students also gain proficiency in utilising different machines, understanding material impacts on prototypes, and conducting necessary tests before finalising their designs. The TAUMs module encourages creativity, imagination, and problem-solving, resulting in positive student feedback and freedom in the learning process [26].

Once students become familiar with prototyping technologies and the Fab Lab environment, they embark on the Moonshot prototype process. Typically, Moonshot problems require years of dedication and investment, but students only have two 25-hour sprints, making it nearly impossible to prototype their solutions fully. Consequently, students are tasked with creating a proof-of-concept or a representative model of their solution.

The Immersive Learning Experience program, facilitated by the Fab Lab "Accelerator & Prototyping Program," guides students through the prototyping process, equipping them with skills and tools for the future of digital fabrication and distributed manufacturing. This program involves mentoring sessions with Fab Lab experts, focusing on selecting appropriate technology, design, and data to address the problem, considering existing knowledge and available resources. The prototyping experience encompasses guided and autonomous sprints, during which students document the fabrication process, and record encountered challenges, decision-making, and potential improvements for subsequent iterations. In the 2022-23 course, two projects were proposed, including "The Box," a prototype aiming to reduce grid

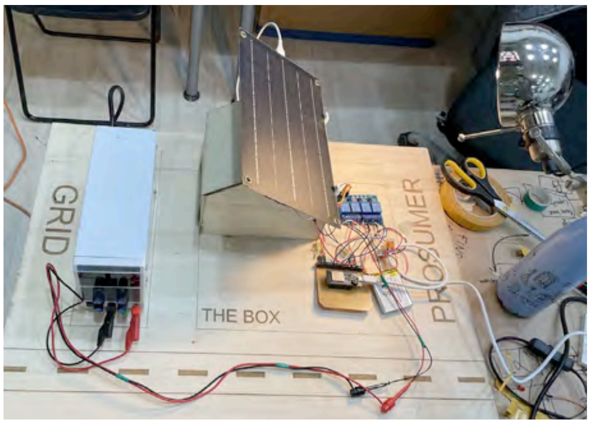

Figure 5. Moonshot Project prototype of the project called “The Box”.

operation costs and enhance performance through a smart grid connection. The prototype, shown in Figure 5, features a low-voltage direct connection microgrid that manages a li-ion battery's charging and discharging behaviour to balance out generation losses from a variable photovoltaic panel. The students acknowledge the prototype's limitations but recognise its potential for future enhancements.

In their final report and presentation, students provided a comprehensive overview of the prototyping process, highlighting encountered challenges, conducted tests, and gained insights. They also outlined the following steps and changes they would implement if the project lasted longer. Rapid prototyping is pivotal in Moonshot Thinking, enabling students to iterate quickly and learn from failures. Collaborating with a Fab Lab adds dynamism and fosters a maker culture perspective.

7 SUMMARY AND ACKNOWLEDGMENTS

This paper presents the results of the pilot implementation of the Moonshot Thinking course for the MSc Innonergy Energy for Smart Cities engineering programme at BarcelonaTech-UPC in Barcelona. This course is challenge-based and adjusted to the Moonshot Thinking approach. Therefore, the methodology of the course implementation of Moonshot Thinking is also presented. The methodology presented above requires a combination of multiple skills and disciplines, coupled with autonomous decision-making by students during the project. This requires a high degree of flexibility on the part of both students and teachers to keep the project's overall goal in mind. On the part of the students, the ability to combine various competencies in an interdisciplinary way is especially challenging. In addition, students are required to come up with unconventional ideas, which is in some ways contrary to what students are required to do in most subjects at university. From the teacher's perspective, the variety of activities requires efficient scheduling of the individual sessions and management of the multiple decision-making processes. A high level of mentoring and interdisciplinary competencies are requested from the lecturers.

The general assessment of the course is positive, and the opportunities for implementing this approach are high, also beyond the engineering sector. Students' motivation for the course is generally high, based on the overall experience of almost three years of implementation. However, a more diverse student profile may result in a more diversified outcome; however, it may also add complexity. Future work will focus on seamlessly systematising the entire methodology and opening it up to a broader range of students as a regular subject at the UPC for energy engineers.

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A POSSIBLE SOLUTION TO AVOID THE CONSEQUENCES OF THE COVID-19 PANDEMIC AND REDUCE DROPOUT IN CALCULUS EDUCATION

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Keywords: *catch-up, calculus, drop-out, COVID-19*

ABSTRACT

The effects of the COVID-19 are likely to stay in education for a long time to come. First year students of 2022 have completed the last two years of their high school education, which are the most important for further studies, during the worst period of the pandemic. Compared to previous years, far fewer students were able to meet the requirements of Calculus 1. Although there was a wide range of support material (interactive online interface, films, notes, elaborate calculation exercises) available to the students, they were not able to catch up and progress independently, regardless.

The calculus course consists of 2×90 minutes of lectures and 90 minutes of practice per week. The lectures are attended by all the students in the year's batch - nearly 200 students - while the exercises are done in groups of 35. In the second semester we introduced a new course for Calculus 2. The 90 minute per week course provides an opportunity to introduce routine calculation methods and thus provide more personalised teaching in small group sessions. New course gives a chance to understand Calculus 2, and thus could reduce the dropout rate.

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In our research, we investigate the effectiveness of this new intervention. We analyse student satisfaction. We will examine the extent to which such a cost-effective intervention helps students to acquire a solid mathematical foundation so that they can successfully overcome obstacles in their studies with less help in the future.

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1. INTRODUCTION

1.1. Pandemic

Several studies have analyzed the short- and long-term effects of the pandemic. (Kaffenberger 2021, Azevedo et al. 2021, Sipos et al. 2020). We are still faced with the long-term effects. Learning loss is the loss of knowledge and skills that can occur when students are not able to attend school regularly or receive high-quality instruction. During the COVID-19 pandemic, many students around the world were forced to learn remotely or miss school altogether, which could lead to significant learning loss in mathematics and other subjects. The long-term impact of this loss could be felt in lower test scores, reduced opportunities for higher education and career advancement, and increased socioeconomic inequality. The shift to remote learning during the pandemic highlighted existing disparities in access to technology among students. Students from lower-income families or those living in rural areas may not have had access to the same quality of computers, internet connections, or other resources as their wealthier or urban counterparts. This could exacerbate existing inequalities in education and limit opportunities for some students to succeed in mathematics and other subjects. With the pandemic disrupting traditional teaching methods, many schools may have had to make changes to the mathematics curriculum in order to adapt. These changes could have long-term effects on students' understanding of mathematics and their preparedness for future coursework and careers. With remote learning becoming more widespread during the pandemic. This could lead to a more permanent shift towards online learning, which could have both benefits and drawbacks for mathematics education. While online learning can offer greater flexibility and accessibility for some students, it may also change the way mathematics is taught and learned in ways that are not yet fully understood.

Knowing the above, we can formulate the following research questions: *How can the harmful effects of the epidemic be reduced in education? How could the learning and teaching of mathematics be made more effective and dropout rates reduced?*

2. DATA

In our study, we present our efforts to address the decline in student performance, which is likely due, in part, to the pandemic. The subjects of our investigation were students who started their undergraduate studies in mechatronics engineering and energy engineering in 2022. Admission to these programs requires high scores, with mechatronics engineering requiring 429 points and energy engineering 348 points out of a maximum of 500 in 2022. The majority of these students enrolled at the Budapest University of Technology and Economics following high school graduation. Consequently, their high school education during the 10th and 11th grades was significantly affected by the pandemic, the impacts of which we observed upon their arrival.

Prior to the beginning of the semester, we administered several entrance evaluations, including tests in mathematics, physics, and an assessment of their geometric thinking skills using the van Hiele test. (Usiskin 1982) The outcomes of these tests were substantially lower compared to the scores achieved by students in the same disciplines in previous years. As we commenced the semester, we offered remedial learning opportunities, such as self-paced online materials and structured courses. Nonetheless, students had to engage in these supplementary learning activities alongside their first-semester coursework. This created a substantial workload for some students, as they were required to attend remedial courses in both mathematics and physics.

Consequently, it is not surprising that this cohort also performed considerably weaker in the first-semester calculus course, which includes differential and integral calculus of single-variable functions, compared to previous cohorts. (We have data on mechatronic and energy engineering students who started their university studies in 2018, pre-pandemic, and 2020, during the pandemic.) It's important to mention those students who selected mathematics in the last two years of high school to be studied for five hours a week instead of the regular three, as well as those who attended special curriculum classes in mathematics, had already learned a significant part of the Calculus1 course material in high school. Unfortunately, our experience over the years is that real understanding of the concepts doesn't happen in high school, with students only mastering certain procedural skills. The Calculusn 1 course material is abundant, and the pace is fast. Those who only studied the intermediate level curriculum in high school face serious challenges at the university.

When contemplating how to assist students, we had to keep several considerations in mind. We needed to think about a solution that is sustainable in the long run, and if successful, could be applied to mathematics education for engineers across other departments and faculties of the university. We couldn't, for instance, consider small-group seminars due to constraints in teaching staff and classroom capacity. Our students already have a high weekly workload, which precluded the possibility of offering assistance courses that are longer than 90 minutes or occur more frequently.

We filled out a questionnaire about their satisfaction with the intervention with the student.

3. METHODOLOGY

Recognizing these challenges, we surmised that our students require additional instructional support to compensate for their deficiencies and to successfully overcome these obstacles. Thus, we introduced a 90-minute practice session associated with the second-semester calculus course. In the Calculus 2 course, students learn linear algebra (vector spaces, matrix arithmetic, systems of linear equations, linear transformations), and they become acquainted with sequences and series of functions (Taylor series expansion, Fourier series). The course concludes with differential and integral calculus of multivariable functions. This course is also considered challenging, with students having to comprehend numerous new concepts in a relatively short span of time and then apply the learned procedures at a skill level. Similar to the Calculus1 course, we provided materials to assist individual preparation for the Calculus 2 course.

In our study, we analyze the effect of supplementing the curriculum with a 90-minute practice session on the study of linear algebra, and whether this aided students in improving their performance. The linear algebra syllabus is taught over a span of six weeks, and it concludes with a test written in the seventh week. Achieving at least 40% on this test is a necessary prerequisite for the student to attempt the Calculus 2 exam. We analyze the results achieved on the linear algebra test in relation to various input parameters.

The mathematics classes are therefore structured as follows in the new system during the semester: there are one and a half hour lectures on Tuesdays and Fridays, for all mechatronics and energy engineering students. Attendance at the lecture is not mandatory, but about 80% of the students are present almost every time. Each student also has a one and a half hour seminar per week, where they practice problem-solving. In these seminars, the students participate in groups of 35. Attendance at the seminars is mandatory. This regular Calculus course was extended with a weekly 90-minute session, which is held immediately after the Friday lecture. The subject is taught by the lecturer. Unfortunately, it was not possible to find a time slot that would have been suitable for the entire cohort, but even so, many students took the supplementary subject.

4. FINDINGS

Figure 1 shows Calculus 1 grades and supplementary course taking. Enrollment in the supplementary course is denoted as follows. The '0' column represents students who didn't meet the preconditions for the Calculus 1 exam, meaning they scored below 40% in the mid-term and end-term tests. As they couldn't register for the Calculus 2 course, the supplementary class (marked as 'Supplementary course' in the chart below) wasn't pertinent to them. Students who satisfied the prerequisite but earned an unsatisfactory grade in the Calculus 1 exam (denoted in the '1' column) could enroll in Calculus 2, as could those who secured at least a passable grade. In all columns excluding '0', we used blue to indicate students who opted for the supplementary course and red for those who didn't take the supplementary class. While a few students couldn't join the supplementary course due to scheduling conflicts, it's not correct to infer that they were among those who scored unsatisfactory grades. Therefore, the trends suggest that students with lower grades in Calculus1 were more likely to opt out of the practice class. Regrettably, it seems that students who struggle with mathematics were less likely to seize the chance to practice than those who navigated the challenges more successfully. We can further analyze the decision of students to enroll in the practice course based on the grades they received in Calculus 1.

Calculus 1 grades

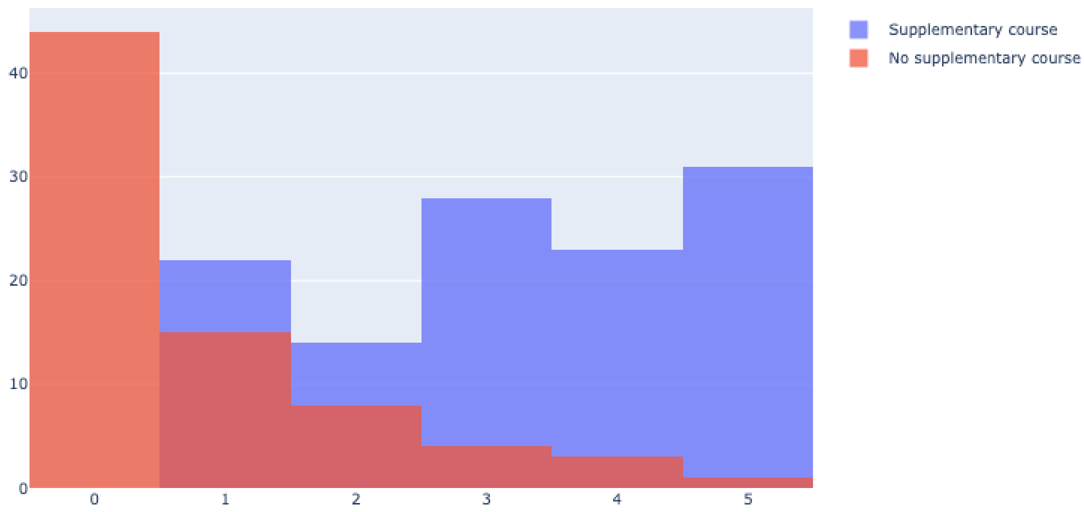

Fig. 1. Calculus 1 grades and supplementary course taking

In this supplementary course, we predominantly present calculation tasks, essentially elaborating on what was covered in the lectures. Our aim was to ensure students attend the seminars having already understood the key concepts, methods, and basic calculation techniques, thereby enabling them to participate more actively, ask questions, and so forth. This course, albeit to a limited extent, also provided an opportunity to make up for past deficiencies. The students tend to attend these sessions in nearly full numbers. Moreover, a few weeks in, there were even some students from parallel calculus courses in other engineering fields who requested permission to attend these sessions.

Students were given the opportunity to provide feedback (3 weeks in) on the supplementary course, including expressing their thoughts in detail and making suggestions. Out of the 41 students who shared their opinions, three did not find the course useful. Two of them believed that it was too demanding to engage with mathematics for another hour and a half after a 90- minute mathematics lecture. One student confessed to not understanding the subject at all. Six students, after three weeks, were still undecided about the usefulness of the supplementary course, though two of them leaned towards finding it beneficial. One student considered the subject too easy. However, 31 students found the course useful. Many of them left detailed comments indicating that they thought the course was a good idea because it helped them understand problem-solving methods better in the seminars.
The linear algebra test took place in the seventh week of teaching. The test was conducted in- person via the cloud-based education platform, EduBase. (Edubase 2023, Szilágyi et al. 2020) The 90-minute test comprised 31 short tasks. It is important for us to track students' progress on each task during online tests, which is why we break down each task into several subtasks. The tasks were varied, testing both calculation skills and theoretical understanding. We deem it important to ensure that the student has understood the teachings. One way of assessing this

is by asking the student to determine whether certain statements are true or false. To deter guessing, incorrect answers attract negative points. Some tasks serve to check basic linear algebra concepts and calculation skills. Achieving 40% was possible just by successfully completing these tasks.

The average score for students attending the supplementary course was 68% (SD 15%), while the average score for those not attending was 53% (SD 13%). The distribution of these results is illustrated in Figure 2. Out of the 143 students who took the test, 116 attended the supplementary course (g2f). Ten students scored below 40%, of which 27 attended the supplementary course. The lowest score was 20.8% and the highest was 82.6%. As can be inferred from the graph, only students who attended the supplementary course achieved scores above 75%.
Using statistical calculations, we proved that the students attending the supplementary course achieved significantly better results on the linear algebra test.

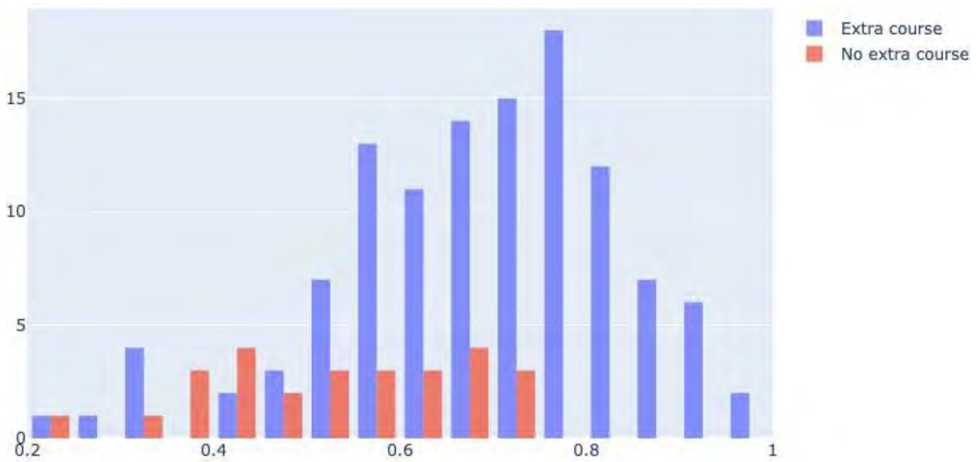

Fig. 2. Calculus 2 first midterm exam results by the groups taking or not taking the supplementary course

It's worth taking a closer look at the academic backgrounds related to the current test results. Figure 3 traces the precursors to the results achieved in the linear algebra test. The graph includes only those students who could take the Calculus2 course. They may have failed Calculus1, but they managed to complete the mid-term tests with at least a 40% score. Each line on the graph symbolizes a single student. The test result can be seen on the right, the Calculus1 grade in the middle, and the entrance points are shown on the left. We are encouraged to see that not only those with the highest entrance points achieved good results in Calculus1. At the same time, it's apparent that even the top-performing entrants could struggle in the first semester, even though they likely covered much of the first semester's material in high school. It's clearly visible that all students with an excellent grade in Calculus1 met the necessary minimum of 40%, and only one student among those with a grade of 4 achieved below- minimum results.

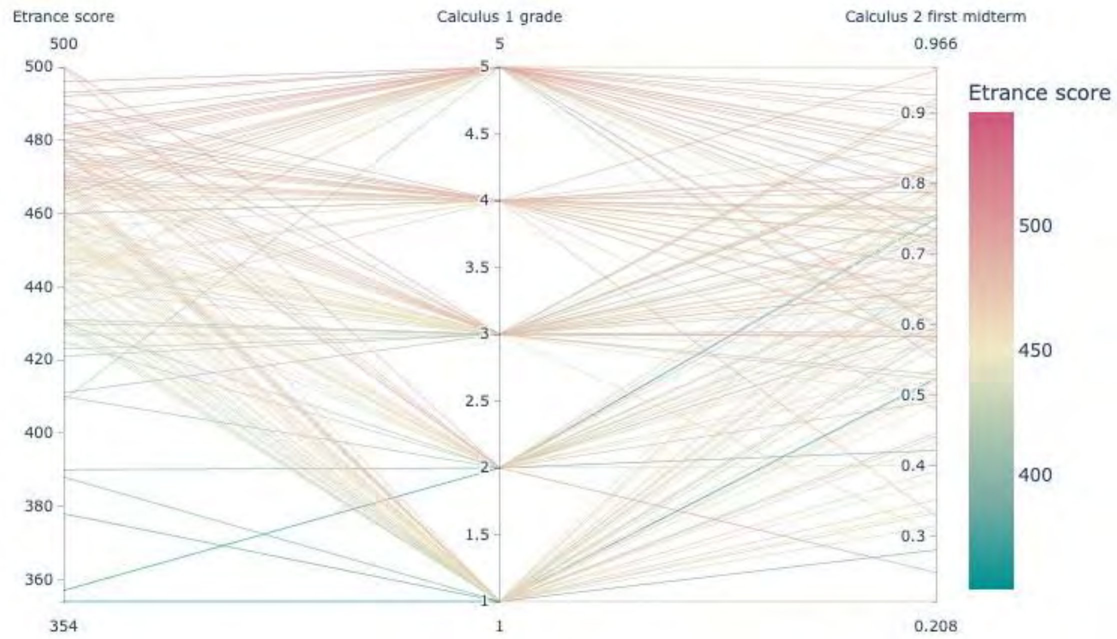

Fig. 3. Entrance score, Calculus 1 grade and Calculus 2 first midterm exam results colored by the entrance score

The notable spread of grades is thought-provoking, and this inspired Figure 4.
Figure 4 examines how test results varied depending on Calculus1 grades and whether or not students attended the supplementary course. The left side of the Sankey diagram shows Calculus1 grades, while the right side represents the converted grades of results achieved in the linear algebra test. The conversion was as follows:

0 – 39%: Fail (1)
40 – 54%: Sufficient (2)
55 – 69%: Average (3)
70 – 84%: Good (4)
85-100%: Excellent (5).

The black color represents students who attended the supplementary course, and gray indicates those who did not. The diagram shows that a larger proportion of students with failing grades in Calculus1 who attended the supplementary course achieved above-minimum test results, with many even obtaining average or good grades. Among students with an average grade in Calculus1, many obtained a good grade (4) on the linear algebra test, and some even reached an excellent (5) level.

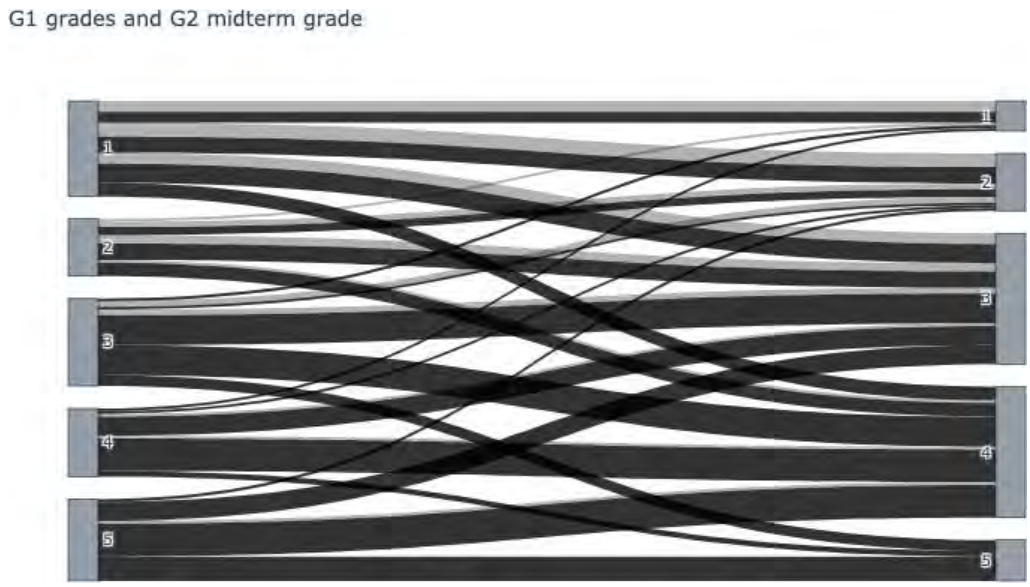

Fig. 4. Calculus 1 final grade and Calculus 2 first midterm exam grade, darker shade is used to represent taking the supplementary class

5. CONCLUSION

Even after analyzing the initial results, we can say that the intervention was successful. We documented the students' attendance at the extra course. At the end of the semester, it will be possible to conduct tests that analyze the relationship between attendance and performance on tests.The number of tests falling below the minimum standard has significantly decreased compared to the first semester, and performances above the minimum level have also improved. We can conclude that a course of this type can greatly assist in reducing student attrition in education, thereby mitigating the impacts of the pandemic. We managed to provide a cost-effective solution that can be easily integrated into any courses to reduce dropout. It is unsurprising that this intervention works. We add more for the students. Increased time on task is widely regarded as greatly beneficial for performance. The full analysis will take place after the semester.

6. ACKNOWLEDGMENTS

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ENGINEERING EDUCATION EVOLUTION

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Conference Key Areas: *Engineering skills and competences, Lifelong learning for a more sustainable world*
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ABSTRACT

Over the years, human needs have been subject to evolution, which translated into economic development and was the result of research, development of knowledge and technology, lifelong learning and the development of skills combined with engineering competences. The paper attempts to analyze the evolution of education with a focus on engineering in the context of the development of technology over the years in conjunction with the significant achievements of technology and engineering craftsmanship. As a result, conclusions were formulated regarding the challenges in the areas of new techniques and engineering solutions that fit into the activities aimed at sustainable development and building a friendly environment for education in the field of technology.

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1 INTRODUCTION

Over the years, human needs have evolved, the satisfaction of which translated into economic development and was possible as a result of undertaken research resulting in the development of knowledge, lifelong learning, the development of technology and skills combined with engineering competences. Evolution and achievements in the field of technology have always been linked to specific engineering knowledge and practice.

Over the years, we have observed changes in the environment, lifestyle and human needs. Motivation plays an important role in human life, which is an inspiration for: acquiring and building as a result of learning through the transmission of masters (teachers), improving through practice (sometimes by trial and error), understanding, designing and building the infrastructure of the environment, proposing better than known solutions as a result of their improvement, proposing categories of new services or products and solutions. An important element of the development of civilization is access to the existing scientific and cultural heritage created by predecessors.

The paper attempts to analyse the evolution of technology development in conjunction with the significant achievements of technology and engineering craftsmanship as a result of the evolutionary approach to the educational process.

2 ENGINEERING EDUCATION EVOLUTION VS BUSINESS

Education is a complex process focused on teaching (equipping people, including robots, with specific knowledge and practice) and learning (the ability to independently acquire knowledge and practice for one's own needs) in accordance with the educational values and goals recognized in a given community and the needs necessary for performing a specific profession or developing one's own interests. The content provided in the education process and the manner of its transmission are related to the developmental phases of a person and their abilities and interests. In practice, various methods of conveying content are known, for example: activating, multifaceted teaching, focused on theory and/or practice, didactic, informational, problematic, practical activating, programmed games. Education can also be focused on various functions, for example: getting acquainted with new material, consolidating specific knowledge, assessing the level of acquisition of specific knowledge and competences.

Over the years, schools and universities, as social institutions that shape human personality, have evolved (a gradual process of change over time) (Bejan 2022), (Gidley and Hampson 2005), (Kujawinski 2010).

From the perspective of years, the following conventionally named structures can be distinguished:

1. no classes, students have a specific social and financial status, teachers have appropriate knowledge and qualifications, the individual relationship between the pupil and the teacher is important,
2. with classes (17th century), the structure is related to the age of students, education available to all social strata (democratization), teachers have the appropriate knowledge and qualifications in the field of its transmission and the necessary infrastructure,
3. traditional type (18th-19th century), a place ensuring peace and free time for learning, collective education focused on mastering the same knowledge and skills

(usually an information monologue, listening and answering), related to the age of students, program and time requirements and organizational are determined,

4. progressive type (20th century), collective education focused on flexible partner forms of cooperation (dialogue) student-teacher in conjunction with a dedicated selection of the content, development of the entire student's personality, stress-free type and individual success, taking into account expectations and cognitive needs and needs dialogue and cooperation of students,
5. contemporary (21st century), a place providing free time with the possibility of comprehensive development of the student's personality in an atmosphere of joy, collective education focused on partner management of students' activity by the teacher and individual cognitive and creative activity of students, supporting their self-development and individuality as a result of independent learning (in terms of: creativity, integration of one's own personality), independent implementation of the task, socialization as a result of dialogue and tolerance, taking into account their psychophysical properties.

Sustainable development should meet current human needs without compromising the ability to meet the needs of future generations, using access to specific resources necessary for life and operation in a safe ecosystem. Physical sustainability is significantly related to knowledge and practice and requires specific research (prior scientific inquiry) and subject technical education.

Until the end of the 20th century, it was a tradition that engineering (technical) knowledge and practice was passed on to students by masters in a long-term process. Forms of documenting knowledge and engineering practice have evolved from oral transmission recorded (remembered) in the human mind, through pictures and printed writing to digital recording. Over the years, technologies evolve, infrastructure and eco-environment change, working conditions and lifestyle change, access to various resources changes. Technology (steam engine) contributed to the mechanization of production (18th century) and the development of processes in the areas of storage, handling and processing. The invention of electricity and the assembly line (19th century) were an inspiration for further new solutions in technology and management with a focus on mass, quality and production costs as well as access to new services and products. The automation of production, the development of mechatronics and activities carried out with less human participation as a result of the use of programmable controllers with memory and computers (20th century) contributed to the significant development and progress of civilization. They were also a source of specific needs and problems and required the search for new solutions. The next step was the implementation of a wide range of information and communication technologies (21st century) in industry and the human environment, resulting in the networking of the environment, the dissemination of artificial intelligence, the presence of cyber-physical systems, digital twin systems and the autonomy of modes that are part of large complex systems.

Over the years, engineering education has also evolved at every stage of this process: from transferring knowledge to shaping skills, as well as educational techniques and technologies. Knowledge and engineering practice changes over the years and becomes outdated and is replaced with a new one or is expanded. Until recently, the knowledge necessary to perform a specific profession (profession) was precisely defined, and mathematics was identified as a way to develop creative thinking by a person. General technical knowledge was supplemented with specialist knowledge and practice dedicated to a specific profession.

The concept of Industry 4.0, aimed at networking complex, distributed and autonomous industrial and business structures, has been translated into the need to provide staff with specific new qualifications and competences as a result of the education process. Significant areas requiring knowledge and practice in the education process were identified, in particular: acquisition, analysis and synthesis of databases and knowledge; intelligent and embedded systems; additive manufacturing; new smart materials; sustainable energy; new business models. The education process requires the acquisition of specific specialist tutoring and skills, communication in the cyber-physical system, adaptation in an environment with variable properties.

In the field of education for the needs of Industry 4.0, there are a large number of publications (Hernandez-de-Menendez et al. 2020), (Himmetoglu et al 2020), (Lewin et al. 2023), (Trevino-Elizondo and García-Reyes 2023) in which the authors present their experiences in the field of educating staff for the digital industry with the perspective of its development in a direction not fully known.

In the 21st century, there has been a significant development and access to mobile technologies and software using artificial intelligence. The new digital twin environment and the new mobile educational potential significantly affect the qualitative and quantitative evolution of education in terms of accessibility in particular and content on a global scale. It has a significant impact on the development of individuals and societies, the creation of new socially and business useful professions. Important in the education process are, among others: activities related to harmony and internal balance; sustainable development with a focus on people, the environment and resources; intergenerational, intercultural and team cooperation; skilful use of global electronic resources of knowledge and information; learning to create and transmit knowledge.

3 EDUCATION VS INTERNET OF EVERYTHING CONCEPT

Specialist chatbot applications (originally chatterbot, 1994) are now known, classified as artificial intelligence (AI) technologies (Thomas 2023), enabling dialogue with a conversation partner in natural language and simulation of interaction (text or voice) with a human as a dialogue partner. They use machine learning (ML) technologies from large amounts of data (deep learning in particular) and natural language processing (Gupta 2023), (Malik et al. 2023). In 2022, OpenAI launched a product called ChatGPT (chatbot with artificial intelligence) (Barrot 2023).

Artificial intelligence is now widely used in decision-making and robotization processes. Applications of artificial intelligence in education (Artificial Intelligence in Education, AIEd) is a new issue that requires research in the field of teacher-student interaction, as well as the use of tools related to artificial intelligence and learning outcomes (education) and areas for their effective learning. The implementation of artificial intelligence (AI) in education is a new challenge for teachers, in particular in terms of learning and understanding a new tool in the context of new applications, ethics, new interactions between users (Wang 2023). Important elements are the relationship between learning and teaching combined with understanding, critical assessment of the decision-making process and the management of mechanisms associated with artificial intelligence and the database input necessary in the software learning process. Complex digital twin systems are being built with a focus on business applications. The designing of digital twin systems for the needs of education is to be considered. The paper (Far et al. 2023) discusses the opportunities, challenges and future directions of new generation communication in the digital system

The process of machine learning with a focus on decision-making processes in technical applications has been significantly developed since the beginning of the 21st century. The year 2020 was a breakthrough in building on-line electronic interactive connections between single isolated people using on-line type dedicated digital tools. These tools were then successfully adapted to the on-line education process, and then in hybrid mode. On-line education allows students to access the content and educational materials in a place and time convenient for them. The observed dilemma is the possibility of assessing the student's active involvement in the learning process with understanding, and then assessing the acquired skills, competences and practice. Another issue is the analysis of students' predispositions in terms of the possibility of assimilating the content transmitted by them, the possibility of increasing their ability to build innovative and practical, environmentally and economically possible solutions that fit into the concept of sustainable development.

One of the solutions for assessing the level of student involvement in the education process is remote monitoring of their physiological state using a non-invasive method of examining the bioelectrical activity of the brain using an electroencephalograph (EEG). The results of the conducted research on the assessment of student activity in the on-line education process using EEG are presented in paper (Gupta 2023). Forecasting the adaptability of students in on-line learning is possible using a modified team machine learning model, which is the subject of paper (Malik 2023).

Chatbots are now considered as a tool for learning language in a natural and human-like way interactive experience. In particular, the ChatGPT tool has the potential to edit and review documents using global electronic resources. Significant issues that require research are the credibility of the documents received, the results of decision-making processes, ethics, and other related issues, including the ability to formulate a task to be performed.

In market practice, until the end of the 20th century, the concept of corporate social responsibility CSR (Corporate Social Responsibility) was developing, focused on building common value while making profits. Since the beginning of the 21st century, the concept of joint responsibility for the environment, society and corporate governance ESG (Environmental, Social Responsibility and Corporate Governance) has been developed. The ESG concept is currently a global trend determining the directions of development of the global economy and social changes. It is part of the concept of the 2030 Agenda for Sustainable Development and the SDGs (European Commission 2018).

The business model is changing from short-term (CSR, focused on achieving the greatest possible profits here and now) to long-term (ESG, taking into account environmental and social goals) (Menghwar and Daood 2021).

Internet of Everything (IoE) is a concept of a network connection of people, processes, data and things with a focus on useful added values obtained on-line. The concept of adaptation the Internet of Things in education has been presented in paper

(Konstantinidis 2021). There is a possibility of creating artificial intelligence ((Bubeck et al 2023), (Hodson 2020), (Shevlin et al. 2019)) at the human level HLAI (Human Level Artificial Intelligence), also referred to as general artificial intelligence AGI (Artificial General Intelligence) for example by: OpenAI, DeepMind, Anthropic), obtained as a result of using an autonomous machine program meeting the Turing Test (a demonstration of the ability to use natural language and indirectly the thinking process) and having the ability to understand, learn and perform any intellectual task in a human-like manner, and then with the ability to evolve into a superintelligence.

The business model is changing from short-term (CSR, focused on achieving the greatest possible profits here and now) to long-term (ESG, taking into account environmental and social goals) (Menghwar and Daood 2021).

The role of artificial intelligence in education and research, with a discussion on the possibility of students achieving better results, is the subject of paper (Alqahtani et al. 2023). Collaborative Technical Education (CTE) approach is being developed on-line with the use of artificial intelligence. The effects of implementing CTE in practice are also being studied (Lakshmi 2023). The use of artificial intelligence in on-line education may result in, among others: greater attractiveness and effectiveness of the education process, individual adaptation of the process to the characteristics and predispositions of the student, increased access to engineering education, motivating teachers to increase the attractiveness of the content provided.

The Internet of Everything is an important platform for the development of Industry 5.0, where the boundaries between different disciplines are blurring, cyber-physical interactivity is significant, the resilience and security of the system dominates, and an approach focused on sustainable development is expected. A discussion on engineering education in the future was conducted in (Broo et al 2022).

Requirements for students by business include: knowledge of foreign languages, solid knowledge in the field of technical sciences, knowledge of current trends in technology, practical skills, soft skills, professional experience, knowledge of new innovative technologies, preparation for international and local cooperation in the field of knowledge and experience exchange. Universities should adapt their curricula to the needs of future employers and the challenges faced by graduates of higher education.

It seems that an approach focused on shaping in the educational process is currently expected (Tadeusiewicz 2000):

1. skills in the field of: constant learning, assimilation of specific data and knowledge by memory and practice for the needs of action in critical situations, the ability to search for specific data and knowledge from resources available in traditional and digital forms, the ability to select the information obtained with a practical focus on a specific goal (need), the ability to use the accumulated own and supplemented knowledge and practice,
2. the ability to critically evaluate content in terms of acquired data and knowledge,
3. methodologies for obtaining and transferring data and knowledge: the Internet as a source of targeted knowledge and data, ICT tools, specialized intelligent robots vs. human beings as a source of data and knowledge.

4 SEFI CONFERENCES VS SENSITIVITY IN ENGINEERING EDUCATION

An example of the sensitivity of the academic community in the field of engineering education are SEFI conferences, which have been held regularly since 1973. The issues raised by the SEFI environment at thematic conferences focused on education were in line with the period of production automation and information and communication technologies, as well as issues focused on sustainable development. Over the years, the question of how to educate engineers prepared for the new complex world of the future has evolved. The questions concerned the model of the engineer of the future and reflection on the role of engineering education for global economies, especially in the context of the concept of sustainable development.

The achievements of the 50 editions of the SEFI Annual Conferences (1973-2022) are focused on engineering education, exchange of views and meetings with educators (mentors, students) and building a European network of contacts (SEFI 1973-2022).

The topics of the conferences were diverse and dealt with current issues in the environment, including in the areas of: Methodology of education in the field of technology; Assessment of the quality of engineering education; Shaping non-technical skills among engineers; The essence of engineering design (1974, 1990); Undertaking technology-oriented research in educational institutions; Continuing education of engineers; Entrepreneurship, management and engineering education; Education of engineers for innovative processes; Professional requirements in the field of technology; Interdisciplinarity and international cooperation in engineering education; Global engineer; Cooperation of industry with engineering universities; The importance of an engineer in a changing world; Engineering education with a focus on lifelong learning; Diversity in engineering education; The impact of information technology on engineering education; Humanities and arts in sustainable engineering education; Creativity, innovation and entrepreneurship for excellence; Blended learning in engineering education.

The 2023 edition of the cyclical SEFI conference is aimed at the next stage of the evolution of engineering education closely related to technology in terms of sustainable development in the global dimension.

5 EDUCATION VS DEMOGRAPHIC CHANGES

In the area of profession and education (also in the lifelong formula), we distinguish the Y and Z generations (Betz 2019). There is a strong correlation and qualitative impact of the previous generation on the next generation.

Generation Y is interested in environmental problems, engages in activities supporting the rational use of Earth's resources and environmental protection, and consumer decisions are well thought out and balanced. He actively uses social media. Generation Z having the ability to use the technology of the real and digital worlds simultaneously, prefers a lifestyle focused on ensuring work-life balance, learns for specific current needs (just in time learning) without a vision and the need for long-term building professional career.

The proposed forms of education should be adapted to the needs of specific generational groups.

6 FINAL REMARKS

In the statement have been characterized the evolution of the education process, in particular in the field of technology, against the background of development and new needs of the industry in the so-called hard areas (technology and related), soft areas (communication, software, management, decision-making, evolution, ethics, resilience), accessibility specific resources and taking into account demographic changes. It is important to shape new relationships between the teacher and the student aimed at triggering innovation and creativity in a dynamically changing environment focused on sustainable development.

The world is changing, the business model is changing, we are changing individually, so the education in engineering process must also evaluate in terms of content and form. An important challenge for the educators community is to notice and react to the demographic changes that are taking place, which are natural generational changes in the life cycle, including in the field of engineering education, professional activity, lifestyle and others. We watched the wonderful original form of the new type of invitation to the next edition of the SEFI Annual Conference 2023 (synchronized sound with the image and mimedramas as a form of communication) in Barcelona in 2022. The engineering education process in a systemic and interdisciplinary approach significantly affects the characteristics of a person, his needs, lifestyle, work ethic, responsibility and other values.

Sustainable development (eco-development) means a new philosophy of global, regional and local development, opposing narrowly understood targeted economic growth, as well as engineering education.

The 50-year achievements of the successive editions of the SEFI conferences indicate the sensitivity of the environment of educators in the field of technical sciences (engineering, technology) to demographic changes and changes taking place in the business environment, in particular in Europe. Tools and methods were sought, with the use of which it was possible to qualitatively improve the engineering educational processes. A European education ecosystem in the field of technical sciences was built, in which good practices were promoted. The analysis of this achievements allows to clearly state that the environment has a significant potential in terms of adaptation to dynamic changes in business and the environment, as well as the ability to formulate current topics of debates.

General engineering education and upbringing have an anthropological, cultural and civilization dimension. They are among the most significant factors of change and creative transformation of man, culture and civilization through the development of technology. Engineering education is one of the most important factors shaping the future of every civilization and ensuring development in science and technology. At the same time, in the education process, our sensitivity to new needs and challenges resulting from the ongoing changes is shaped.

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FROM ROOKIES TO SYNTHESIS: AGILE SOLUTIONS FOR SUSTAINABLE DOCTORAL STUDIES

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ABSTRACT

Modern doctoral education in engineering lies at the intersection of three topical phenomena: firstly, the surge of wicked sustainability concerns and the subsequent burgeoning demand for cross-disciplinarity. Secondly, the rapidly developing new technologies and global knowledge economy provide a thriving problem-solving potential, although – thirdly – this requires proactive and innovative collaboration beyond the scope of a single discipline. Thus, doctoral education needs new practices to ensure that students are equipped with new kinds of competencies to solve unpredictable and wicked sustainability problems. In order to reach these demands, we need to favor collaboration over competition. Here we approach these issues by presenting key findings from a five-year empirical study on doctoral education in engineering. Data were collected by using a journey mapping method on recently graduated doctors in engineering at Aalto University, Finland. Students from the examined research group were compared with a control group. The data were clustered and the main factors contributing to the individual journeys were

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analyzed. Community, colleagues, and collaboration turned out to have the strongest positive impact on their doctoral journey (average +1.26, scale -3…+3), and they were distributed across the thesis process. Most observations were related to external academic factors, such as funding and journal decisions. Additionally, we present research group practices, such as “Rookies club” and "Synthesis groups" that strengthened students’ resilience and internal support on these factors. These practices initiated positive interdependencies among the students and supported sustainable supervision practices. Our results are applicable to a wide range of doctoral education.

1 INTRODUCTION

Modern-day engineering education holds a high potential regarding bold actions for advancing sustainability. Firstly, the surge of wicked societal and environmental problems, their cross-disciplinarity and complexity, as well as potentially useful research outputs to tackle them creates an increasing opportunity for creative multidisciplinary collaboration and integration in research (Tejedor, Segalàs, and Rosas-Casals 2018).

Secondly, the rapidly developing new technologies, global knowledge economy, and modern research hold the potential to leverage and expand integrated understanding of, for example, the nature of human and biophysical systems and their complexities (Stock and Burton 2011; Milojević 2015). Researchers are expected to make significant contributions to frontier knowledge in increasingly complex situations (Durette, Fournier, and Lafon 2016). Interdisciplinarity is integral for developing and utilizing new technologies, as well as tackling the current complex environmental and societal problems that go beyond the scope of one discipline (Townsend, Pisapia, and Razzaq 2015; McCance et al. 2023). Whereas agile and deep learning is already a cornerstone for professional success in knowledge-intensive jobs, the learning-to-learn paradigm is widely setting aside from the aged learning-to-do approach to education and professionalism (Bormann, Williams, and Minkova 2017).

2 METHODOLOGY

2.1 Case study in engineering

The empirical data depicts a timeline of visualizations of twelve doctoral students regarding their doctoral thesis process. The data were collected in small group workshops and the participants were soon-to-be graduating or recently graduated from the same doctoral programme in Aalto University, Finland. The workshops were organized in person or online using Zoom and Miro boards. Before the workshop, the participants were asked to reflect their doctoral thesis journey and collect necessary documents, such as notes. Each participant produced their own journey map: first, they were asked to document activities, milestones, resources, persons, touchpoints and other observations of their journey into individual sticky notes and organize them in chronological order. Next, the participant graded their individual observations following Nilsson's classification (Nilsson, Griggs, and Visbeck 2016) from -3 indicating the strongest negative impact (cancelling or making thesis work impossible) to +3 indicating the strongest positive impact (the action is inextricably linked to progress), see Table 1 for detailed description of these observations.

Table 1. The classification of the student's observations based on their contribution to the work and wellbeing. Each student graded each of their observations individually.

Grade	Explanation
+3	**Indivisible**. The strongest form of positive contribution, in which the action is inextricably linked to the advancement of the thesis and/or wellbeing.
+2	**Reinforcing**. Aids the achievement of a thesis goal. One objective directly creates conditions that lead to the achievement of another goal.
+1	**Enabling**. Created conditions that further the research/thesis goal and/or wellbeing. The pursuit of this one goal enables the achievement of another goal.
-1	**Constraining**. Limits options on research/thesis goal. The pursuit of this goal sets a condition or a constraint of the achievement of research/thesis goal.
-2	**Counteracting**. Clashes with the research/thesis goal and/or wellbeing.
-3	**Cancelling**. Strongest form of negative interaction. This factor makes it impossible to reach research/thesis goal and/or strongest negative impact on wellbeing.

The students used this grading system to both analyze and describe their own journeys. This process provided results which are discussed in Section 3.

2.2 Doctoral students

The twelve students formed two groups of equal size.

Group 1 consisted of six doctoral students from a research group, the culture of which emphasizes belongingness, subsidiarity, and co-creation of practices for peer learning and strong community. Each doctoral student had a diverse team of advisors led by the supervising professor. The students worked in a project that focused on strengthening doctoral education and interdisciplinary peer learning practices (Taka, Verbrugge, and Varis 2021).

Group 2 consisted of six doctoral students from other research groups in the same unit, but who had no collaboration with the Group 1 students. These students were working in more traditional research groups and doing more independent research. Furthermore, they were actively supervised in, for example, weekly one-to-one meetings with their supervisor as well as in weekly research seminars.

Each student had one to three thesis advisors including the supervising professor (Group 1 average 2.3; Group 2 average 1.3). Eleven students published an article-based dissertation that consisted of 4.2 peer-reviewed publications on average (4.0 in Group 1; 4.5 in Group 2). The average graduation time of the studied doctoral students was 5.3 years (target time 4 years; range 4—6 years). Notably, the number of doctoral students who had completed their master's degree in the same unit was five in Group 1, and only one in Group 2.

2.3 Data analysis

All the workshop data were collected into canvases and visualized in Miro online whiteboard tool. The participants were coded with running identification number (s01 to s12) and the notes were anonymized. All the notes (N=407) were manually clustered into eight key themes and analyzed separately for pre-midterm and post-midterm phases, and they were also analyzed in a chronological order. All the data analysis and visualizations were performed in RStudio.

3 RESULTS

3.1 Key contributing factors

The obtained data highlights the diversity of individuals and their experiences in their doctoral journey. On average, students in Group 1 made 31 observations, compared to 37 in Group 2. The observations were clustered into eight thematic groups (Table 2), and this paper focuses on the group with the most positive contribution to the students: the community and colleagues. The average rank of these observations was +1.26, median +2 (N=36, 49% from Group 1) university activities. The other clusters with median rank above zero were external academic factors (such as research visits, conferences, and journal or funding decisions), research (research activities, such as data collection, experimentation, and scientific writing), researcher skills and identity, and the university activities. The factors with an average rank below zero were supervision, external non-academic factors (family, spare time and pandemic-related issues), as well as personal emotions and self-management.

Table 2. The main clusters of doctoral students' observations and their mean and median values. The scale is from -3 to +3, and in each cluster, the minimum value was -3 and the maximum +3. Group 1 indicates the share of observations in each cluster presented by the Group 1 doctoral students. The share of positive and negative observations in each cluster is also reported.

	N	Mean	Median	Group 1 %	Positive / negative
Community, colleagues, collaboration	37	1.26	+2	51%	78 / 22%
External academic	60	0.98	+1	60%	72 / 28%
Research	57	0.87	+1	46%	77 / 23%
Researcher skills and identity	42	0.36	+1	35%	62 / 38%
University activities	50	0.19	+1	66%	56 / 44%
Supervision	49	-0.07	-1	18%	47 / 53%
External non-academic	57	-0.27	+1	37%	37 / 63%
Personal emotions and self-management	54	-0.37	-1	48%	35 / 65%
Total	**407**	**0.35**	**1**	**45%**	**57 / 43%**

3.2 Research group culture for collective success

The research project focused on developing practices for interdisciplinary research excellence, peer learning, and holistic wellbeing. Critical factor for this was the group culture, which the head of the research group defined using a subsidiarity principle; it holds that a higher ranking body should aid the lesser body to coordinate activities of the greater community, and that decision-making should be taken to the lower appropriate level and closest to those affecting (UNDP 1999).

Furthermore, the group was designed with beneficial and low-risk interdependencies that favored collaboration over competition. The supervisors invested effort in ensuring doctoral students' funding for the entire project, and the Group 1 students described this as a critical factor in allowing them to focus on long-term research planning and risk-taking. However, the students were lacking funding-related pressure and experience in applying funding, which may challenge them in their future work. Notably, the secure funding may explain the low grades in observations of external non-academic factors, as students in Group 1 may have been overly comfortable in their own premises and the team.

To successfully apply the subsidiarity principle into practice, the managers designed "a community tax" concept, which allocated 5% of each research group member's work time for the common good. There was no specific follow-up for this, but it was mainly based on a common agreement. In practice, this turned out to be challenging for a few colleagues who had been working in the team for a longer period. These new culture-building norms and practices were experienced as artificial and unnecessary in a situation that was experienced as well-functioning for personal purposes. In practice, the group needed novel practices and a culture that would be agile in a highly dynamic, academic context. In fact, the research group grew from ten people just before the project to more than thirty by the end of the project.

These group-level norms were critical in ensuring sustainable practices and holistic well-being in the group. It was critical especially for two reasons: first, it strengthened the space for individuals' psychological safety and belongingness. Belonging to a team is one of our basic psychological needs and personal motives, strongly contributing to group-level cohesion (Ryan and Deci 2000). The well-defined, co-developed norms were highly beneficial in new employee onboarding, as they were immediately included in the group functions with a high respect and appreciation of everyone's diverse competencies. Second, these norms set the scene for initiating and facilitating collaboration and peer learning practices.

3.3 The matrix-based activities of the research group

In Group 1, the collaborative practices and interdependencies among researchers were designed across two dimensions. Firstly, the research group level practices focused on intragroup collaboration, support, and peer-learning (Figure 1). Following the subsidiary principle, each group identified their topical needs and co-developed practices to meet those needs. These workshops were organized at least annually, and the activities were iterated based on active reflection from past experiences. These collaboration activities – called 'puuhas', meaning light everyday task in Finnish, ranged from weekly research seminars to research dissemination, skills clinics, and nature walks.

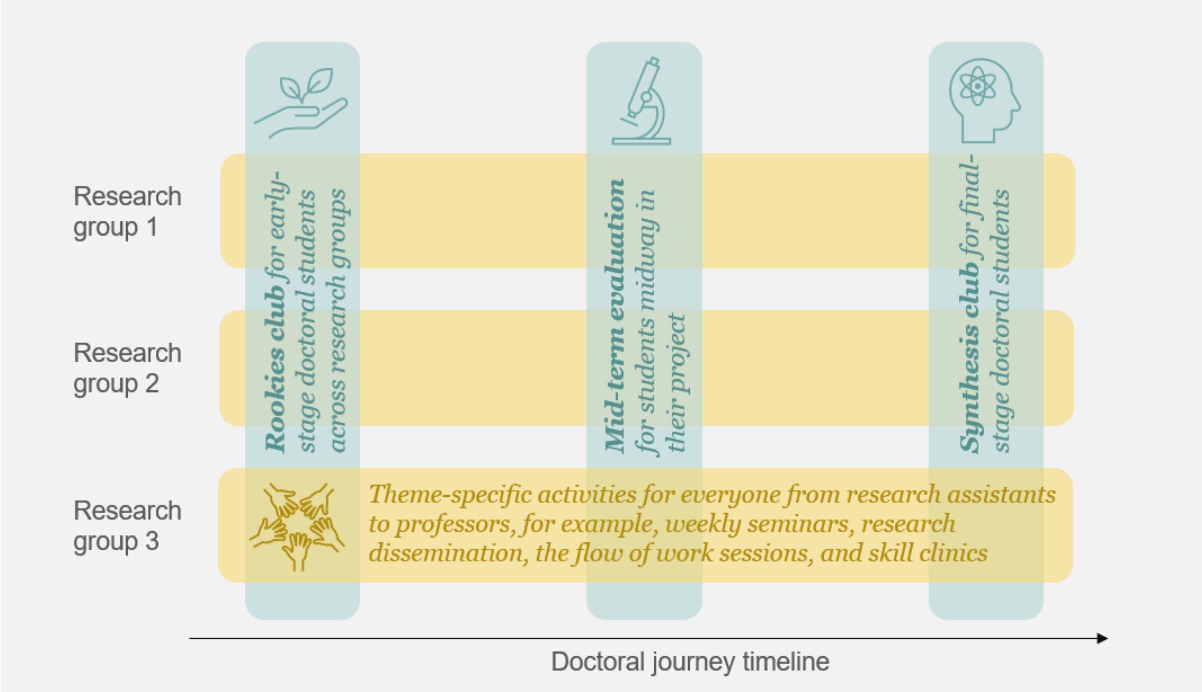

Figure 1. The schematic illustration of designing the peer learning and collaborative practices for research groups and for the interteam learning. The model encourages intra and intergroup collaboration and favors interdependencies over competition. The horizontal, research group specific activities are continuous, focusing on the themes, methods, and depth, whereas the vertical activities focus on interdisciplinary and novel collaboration, focusing more on the stage of doctoral studies. They are fixed-term and target on the needs on that specific stage.

Each team member was assigned to one puuha, and these small groups designed their way to coordinate and facilitate the activities. The hybrid hierarchy allowed the professors to step back and let the doctoral students and postdocs learn about management, planning, organizing, and communication, among many other skills. The professor described how both the doctoral education and research group culture benefitted from these practices: supervision was proceeding in stages, students were open and active in seeking for collaboration, the communication was planned and systematic. For students, the established group profile and reputation were important in supporting their own identity development.

The other dimension of the activities was based on the stage of doctoral students' studies. These activities mainly facilitated intergroup activities and utilized the unwritten, experience-based knowledge in the groups. Rookies club was a group for new doctoral students, focusing on providing scaffolding, peer support, and critical knowledge for the first steps in their research and learning. The monthly meetings focused on providing support and a safe space for discussions. These meetings were later also used for working together and for creating a flow of work time. Synthesis groups were offered for those starting to write their article-based thesis summaries. Based on our research, this was often the time of an existential crisis, poorly structured process, and loneliness. Furthermore, in the beginning of the third year in their studies, students prepared together for the official midterm evaluation and presented their progress reports in pairs.

The Synthesis group aimed to provide structure for the writing and synthesizing process. Students from the previous groups had documented their tips and advice, and these were collected into a “road map” describing the critical steps and things to consider. The groups collected students from different research groups, allowing the groups to focus more on the process, rather than the research topic. Peer support focused on theoretical frameworks, research communication, and disseminating the work. The assumption was that support for the research topic and novelty would come from the supervisors.

These above-mentioned activities were not piloted in the control group, which resulted in student observations of lost and loneliness. For example, some students in Group 2 were lacking supervision, especially with the cohesion of the work. They were also struggling to find information about all the requirements and practical tips, while lacking culture of knowledge on where to ask for help. During the midterm evaluation, students expressed feelings of uncertainty and lack of overall focus on their work.

One student from Group 2 expressed that their supervisor was too busy to support in the final stretch, and they were not comfortable with the level of complete independence. Students had feelings of not sufficient progress.

4 SUMMARY AND ACKNOWLEDGMENTS

This paper presents research-group level sustainable practices that focus on peer learning, interdependencies, and holistic wellbeing. First dimension is the research group level, focusing on continuous practices to initiate collaboration, deep learning the field, and strengthening peer support. The second dimension focuses on practices targeted on the needs on a specific stage of the studies. These fixed-term practices aim to transfer knowledge and provide support from senior colleagues in the team. These practices are easy to initiate by following the subsidiarity principle and an inclusive culture, and a commonly agreed investment in such activities.

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POTENTIAL FOR MEANING MAKING OF THE MATHEMATICS IN ENGINEERING: THE CASE OF LINEAR MODELS IN STATISTICAL SIGNAL PROCESSING

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ABSTRACT

Meaning making of the mathematics involved in engineering problems can boost students' learning, in general. Zooming in to a particular engineering course in signal processing, called Estimation, Detection, and Classification, given to 3rd-year students at NTNU, the potential for meaning making has been investigated using a mix of directed and summative content analysis methods for the specific content Linear models. The findings show that an attempt is made to present the linear model-based estimators in reduced complexity, i.e., without detailed, rigorous proofs that demand solid prior knowledge and concept image from the learner. The 18-page chapter is dominated by advanced mathematical symbols from different mathematical concepts with higher cognitive demanding tasks and activities, which can increase complexity in meaning making. Four types of representations (context, verbal, symbols, and graphs) and multimodal approaches (writing and mathematical symbols) are used to create the potential for meaning making to the user. Symbolic representation dominates the pages creating a higher extraneous cognitive load on the learner. Whereas examples and contexts contribute to lowering the complexity in the potential for meaning making of the mathematics in the chapter. This preliminary study does not include the instructors' and students' active meaning making processes yet.

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1 INTRODUCTION

Mathematics is viewed, in general, as a service subject for engineering fields [1]. Understanding mathematical contents like algebra, calculus, partial differential equations, and other mathematical concepts could facilitate success in engineering studies [2, 3]. [2] investigated what engineering faculty members meant about "mathematical maturity" to get their desired outcomes from core mathematics courses.They found out that "the mathematically mature" student would have strong mathematical modeling skills supported by the ability to extract meaning from symbols and the ability to use computational tools as needed" p. 97. However, many engineering students perceive mathematics instrumentally and think of it as a subject of many rules and procedures [1,5] and struggle to make meaning of mathematical content in their various engineering studies [4]. Such belief and attitude could lead to perceiving the subject as an obstacle to engineering study [2, 4].

Guided by three research questions, [1] reviewed research journals, books, and proceedings to understand the recent state-of-the-art overview of the emergent field of mathematics in engineering. They aimed to develop a deeper understanding of the characteristics of "the current teaching and learning practices in mathematics that can inform the design and implementation of future innovative practices in engineering education" p.163. One of the research questions is about the 'resources' used and if they are well suited for innovative practices. The term 'resource' is defined as anything that can 're-source' the learning activity of learners, in this case, engineering students [1, 6]. Hence, resources include textbooks, educational technologies, and others. This preliminary study focuses on a textbook used by engineering students.

[7] conceptualized a textbook as a learning tool embedded in a tertiary educational setting. For Randahl, "by a learning tool mean a cognitive tool that promotes cognitive processes related to meaningful learning of mathematics" p. 34. Meaning making of the mathematics involved in a textbook could be one aspect of boosting students' learning and innovative skill [8, 9], for engineering students as well. We are especially interested in textbooks as learning tools for the student's potential meaning making of the given curriculum [7, 9,10]. As a cognitive tool, textbooks can facilitate or hinder students' meaning making process, which can also be explained via the concepts of cognitive load and cognitive demand.

Using a particular engineering course in signal processing, and specific content in a textbook, Linear models, the potential for meaning-making has been investigated. Linear models is one of the most critical classes of models that represents a more complex phenomenon in a simplified abstraction. Several service courses in mathematics and statistics cover this content. Meaning making of this model is expected from the students in several engineering problems. Hence, the potential for the meaning of the textbook on the linear models of this textbook is investigated. The data is analyzed using directed and summative content analysis methods [11]. The aim is to investigate the possible meaning in the student textbook used for teaching the linear models-based estimator in the engineering course guided by the research questions: how is the linear model-based estimator presented in the given course material? And what are the potentials for meaning making of the mathematical contents in connection to the content linear model-based signal processing estimation problems?

2 THEORETICAL FRAMEWORK

2.1 Meaning making in Mathematics

By defining meaning making as " the process by which people interpret situations, events, objects, or discourses, in the light of their previous knowledge and experience" [12:1809], asserts learning as a meaning making process in light of the different educational, psychological and philosophical perspectives which includes: cultural-historical psychology, pragmatism, constructivism, and social constructionism. From the standpoint of these perspectives, "to learn something means to establish a meaningful relation to the subject matter so that it makes sense to the learner" [12:1809]. [13] claimed, from a social-cultural perspective, "Meanings of concepts are not necessarily conceived of as referring to something "objective" in the world but as something embedded in the social and cultural practices in which they evolve" p. 150. Hence, meaning making is a dynamic process, and mediating artifacts, such as textbooks, can facilitate learning [8, 9].

For [5], understanding mathematical concepts can provide two different meanings: instrumental and relational. The learners make instrumental meaning, i.e., learning an increasing number of fixed plans, by which they can find their way from particular starting points to required finishing points. While relational meaning, according to [12], consists of building up a conceptual structure (schema) from which its possessor can produce unlimited plans for getting from any starting point within his schema to any finishing point making meaning making is a complex process. [8] expressed the difficulty of discerning students' conceptual understanding and preferred to investigate students' mathematical meaning making. To characterize the process, [8] connected the study of students meaning making with the SEFI/Niss competence framework, which has eight subcategories [14].

2.2 Potential Meaning Making of textbooks

In a doctoral study, [15] investigated learners' meaning making as a combination of i) their prior knowledge, ii) the information they access as they progress with the content, iii) the resource available to support their learning, and iv) the constraints imposed on that content by the wider environment. Textbooks are one of the resources that provide opportunities to facilitate the meaning making process. In another doctoral study titled, 'Engineering students approaching the mathematics textbook as a potential learning tool – opportunities and constraints', [7] conceptualized the textbook as a learning tool embedded in a tertiary educational setting. For [7], there are three perspectives on the process of approaching the textbook as a learning tool, that is, as potentially as a meaning making tool: the epistemological perspective referring to the nature of mathematical knowledge; the cognitive perspective focusing on the individual student ability to engage in the making process which can be related to the prior knowledge of the student as well as the concept definition and concept image; and didactic perspective focusing on the way the textbook is embedded in the institution. The assumption is that the learners are expected to use the textbook as a cognitive tool that promotes cognitive processes related to the meaningful learning of the mathematical content.

In general, textbooks facilitate the student's meaning making process at different stages of learning. Intending to explore the role of the textbook in a Swedish classroom as the teacher-student interaction, [16] used three theoretical perspectives: the choice of educational content and contextualization, interaction to negotiate meaning making, and the use of the textbook as a potentially implemented curriculum. According to [17], meaning is a difficult concept, but it can come to presence through signs or semiotics. [9] used a multimodal approach to learning, where meaning making is central to textbook research. Assuming that modes (Writing, images, mathematical symbols, speech, moving images, etc.) carry the potential for meaning making, [9] investigated the potential for enabling communication between a Year 1 child Swedish and textbooks. The study showed a great complexity in the potential for meaning making in children's work with mathematics textbooks. Another study by [7], focusing on teachers' and students' interaction as influenced by textbooks in a grade eight classroom in Sweden, claims that textbooks are designed in a certain way with a guiding view of learning, stated explicitly or not. [7] questions if textbooks may be a source for meaning making by themselves without a teacher or facilitator/tutor, i.e., the textbook might not have a potential for meaning making, and the student can ignore it. However, one can argue that meaning making is directly related to prior knowledge of the learner, and much is expected from a tertiary-level student to make meaning by interacting with the book's author.

At a tertiary level, as noted above, [7] situated the study in the context of the basic mathematics course taken by first-year engineering students to identify and explore the factors that might influence the role of the textbook proposed to first-year engineering students. In other words, the study focused on the potential of meaning making of the textbook embedded in the educational setting offering the basic mathematics course. Since engineering students are more mature than the learners at primary or secondary school, they can engage in the meaning making process individually or in a group with and without a facilitator or teacher. The problem, at this level, could be that different mathematical contents might show up in a single mathematical task, like in the linear model, a case considered in this study.

2.3 Cognitive load and Cognitive demand

[18] reconceptualized mathematical cognition as a process of ascribing meaning to the mathematical objects of one's thinking and claimed that "mathematics cognition does not merely involve the attempt to recognize a previously unnoticed meaning of a concept but the attempt to ascribe meaning to the objects of one's thinking," [18:1234]. Instead, mathematics cognition evolves due to contextualization, complementizing, and complexifying. Such a complex process is a cognitively demanding activity. [19] characterized the cognitive demand of mathematical tasks (activities) into four levels: memorization, procedures without connection, procedures with connection, and doing mathematics. In light of these, an advanced meaning making process demands higher cognitive levels. John Sweller developed a cognitive load theory (CLT) in 1988. Cognitive load refers to a user's total amount of information the working memory can hold at any given time [20]. Hence working memory has a limited capacity. There are three types of cognitive load: Intrinsic, Extraneous, and Germane. Intrinsic load refers to the inherent difficulty level associated with a specific instructional topic that can vary from the learner's prior knowledge and experience [21]. At the same time, extraneous cognitive load refers to how information is presented to the learners to engage in working memories [20, 21]. Germane cognitive load is the learners' processing, construction, and automation to comprehend the content (material). Only these Germane cognitive

load is seen as favorable for learning [20]. Textbooks as cognition tool can create different cognitive loads.

2.4 Linear Models

This research focuses on the case of linear models. A large number of signal-processing estimation problems can be represented by a linear model [22]. This data model allows us to easily determine the estimator and its performance for both the classical and Bayesian approaches.The classical general linear model assumes that the data to be described as given in *Eq. (1).*

$$\mathbf{x} = \mathbf{H}\boldsymbol{\theta} + \mathbf{w} \tag{1}$$

where $\mathbf{x}$ is an $N \times 1$ vector of observations, $\mathbf{H}$ is a known $N \times p$ observation matrix $N \times p$ of rank p, $\boldsymbol{\theta}$ is a vector of $p \times 1$ vector of parameters to be estimated, and $\mathbf{w}$ is a $N \times 1$ noise vector with a Gaussian Probability Distribution Function (PDF) with mean zero vector and covariance matrix $\mathbf{C}$, $\boldsymbol{\mathcal{N}}(\mathbf{0}, \mathbf{C})$. The PDF of $\mathbf{x}$ is

$$p(\mathbf{x}; \boldsymbol{\theta}) = \frac{\mathbf{1}}{(\mathbf{2}\boldsymbol{\pi})^{N/2}\, \boldsymbol{det}^{\mathbf{1}/\mathbf{2}}\,(\mathbf{C})} \,\mathbf{exp}\left[-\frac{\mathbf{1}}{\mathbf{2}}\,(\mathbf{x} - \mathbf{H}\boldsymbol{\theta})^{T}\mathbf{C}^{-\mathbf{1}}(\mathbf{x} - \mathbf{H}\boldsymbol{\theta})\right] \tag{2}$$

The Bayesian linear model further assumes that $\boldsymbol{\theta}$ is a $p \times 1$ random vector with Gaussian PDF, $\boldsymbol{\mathcal{N}}(\boldsymbol{\mu}_{\theta}, \mathbf{C}_{\theta})$, independent of $\mathbf{w}$. When assuming the linear model, it is possible to determine the optimal estimator $\hat{\boldsymbol{\theta}}$. The performance of any estimator obtained is critically dependent on the PDF assumptions.

3 METHODOLOGY

3.1 Context and Selected Textbook

This study is conducted in the Norwegian University of Science and Technology (NTNU) context. The author, a former doctoral candidate in the signal processing group, took the initiative to investigate the textbook used in a course in Statistical Signal Processing. The book Fundamentals of Statistical signal processing, Volume I, by [22], is one of the main course materials used in the mentioned course. It is selected to study the potential meaning making of the mathematics in engineering for convenience (convenience sampling): the researcher has taken the course and assisted it for two years during the doctoral study a decade ago. The textbook is heavily influenced by different mathematical contents, a natural candidate to start studying about meaning making of the mathematics in engineering. It consists of 15 chapters. According to the author, the book is intended as a graduate one-semester course with several student tasks (including the explanation, worked examples, and problems). For the present study, only chapter four, Linear Models, is considered as a key model used for several signal-processing problems in areas like estimation, detection, system identification, pattern recognition, machine learning, etc.

3.2 Framework for analysis

Qualitative content analysis is "a strict and systematic set of procedures for the rigorous analysis, examination, replication, inference, and verification of the contents of written data" [23]. In this case, it can be used to study the potential for meaning making a document or textbook. According to [11], there are three kinds of content analysis: conventional, directed, and summative. Conventional content analysis is used when researchers try to avoid using preconceived categories; directed content analysis is guided by existing theory or prior research by identifying key concepts or variables as initial coding categories; and in summative content analysis, keywords are selected based on previous research or the researchers' interests [11, 20]. This study follows a mix of the second and the third approaches since Keywords derived from the researcher's interest based on the literature review are used for analysis. In this preliminary study, neither the engineering student's engagement in the meaning making process nor the teachers' work to facilitate the meaning making process is not included. Rather a mere look at the textbook used for an engineering course and the potential for meaning making is investigated. Table 1 summarizes the researcher's choice to analyze the contents of the chapter selected from the mentioned textbooks.

Table 1. The framework for textbook analysis.

Literature	**Meaning Making in mathematics**	**Keywords**
[15]	As a combination of i) their *prior knowledge*, ii) the information they access as they *progress with the content*, iii) the resource available to support their learning, and iv) the constraints imposed on that content by the wider environment.	Prior knowledge, progress with the content, resource
[8]	In light of the eight mathematics competencies: thinking mathematically, Reasoning mathematically, Posing and solving mathematical problems, *Modelling mathematically*, *Representing* mathematical entities, Handling mathematical symbols and *formalism*, Communicating in, with, and about mathematics, and Making use of aids and tools.	Representing, Modelling, mathematical symbols and formalism
[9]	A textbook with a *multimodal approach*, broadening mathematics representation, provides an individual potential for meaning making.	A multimodal approach
[7]	The epistemological perspective, including *conceptual and procedural knowledge*. The cognitive perspective, including the notions of previous knowledge, concept image, concept definition, and the didactical perspective, characterizes the educational setting that creates teaching-learning environments.	Conceptual and procedural knowledge
[5]	Three types of *understanding*: Instrumental understanding, and Relational understanding	Understanding
[19]	The *cognitive demand* of mathematical tasks (activities) into four levels: memorization, procedures without connection, procedures with connection, and doing mathematics	Cognitive demand
[20, 21]	There are three types of *cognitive load*: Intrinsic, Extraneous, and Germane.	Cognitive load

4 ANALYSIS AND DISCUSSION

4.1 Minimum Variance Unbiased (MVU) estimator for the Linear Model

Linear models allow us to model several signal-processing problems like estimation, detection, pattern recognition, machine learning, etc. In Chapter 2, [22] provided the minimum variance unbiased (MVU) estimator, which produces values close to the truth most of the time. In Chapter 3, for its easiness, the Cramer-Rao Lower Bound (CRLB) is presented as a bound on the variance of any unbiased estimator. In Chapter 4, [22] assumed a linear model, defined in equation (1). Steven M. Kay argues that a significant number of signal processing estimation problems can be represented by a data model that allows us to determine the MVU estimator quickly.

The chapter first provides an introduction and summary section and then provides the development of the MVU estimator for the Linear Model. Given the linear model in *Eq. (1),* a key model with PDF of $\mathbf{x}$ given in *Eq. (2)*, then $\hat{\boldsymbol{\theta}} = \mathbf{g}(x)$ will be the MVU estimator if:

$$\frac{\partial \ln p(\mathbf{x};\boldsymbol{\theta})}{\partial \boldsymbol{\theta}} = \mathbf{I}(\boldsymbol{\theta})(\mathbf{g}(\mathbf{x}) - \boldsymbol{\theta}) \quad (3)$$

for some function $\mathbf{g}$ and $\mathbf{I}(\boldsymbol{\theta})$**,** which is the Fisher information matrix that determines the characteristics of statistical estimation. The linear model *Eq. (3)*

$$\frac{\partial \ln p(\mathbf{x};\boldsymbol{\theta})}{\partial \boldsymbol{\theta}} = \frac{\partial}{\partial \boldsymbol{\theta}} \left[-\boldsymbol{ln}\, (2\pi\sigma^2)^{\frac{N}{2}} - \frac{1}{2\sigma^2} (\mathbf{x} - \mathbf{H}\boldsymbol{\theta})^T (\mathbf{x} - \mathbf{H}\boldsymbol{\theta}) \right] \quad (4).$$

$$= -\frac{1}{2\sigma^2} \frac{\partial}{\partial \boldsymbol{\theta}} \left[\mathbf{x}^T\mathbf{x} - 2\mathbf{x}^T\mathbf{H}\boldsymbol{\theta} + \boldsymbol{\theta}^T\mathbf{H}^T\mathbf{H}\boldsymbol{\theta} \right] \quad (5).$$

Further using identities,

$$\frac{\partial\, \mathbf{b}^T\boldsymbol{\theta}}{\partial \boldsymbol{\theta}} = \mathbf{b} \quad (6).$$

$$\frac{\partial\, \boldsymbol{\theta}^T\mathbf{A}\boldsymbol{\theta}}{\partial \boldsymbol{\theta}} = \mathbf{2A}\boldsymbol{\theta} \quad (7).$$

for $\mathbf{A}$ a symmetric matrix,

$$\frac{\partial \ln p(\mathbf{x};\boldsymbol{\theta})}{\partial \boldsymbol{\theta}} = -\frac{1}{\sigma^2} \left[\mathbf{H}^T\mathbf{x} - \mathbf{H}^T\mathbf{H}\boldsymbol{\theta} \right] \quad (8).$$

Assuming that $\mathbf{H}^T\mathbf{H}$ is invertible

$$\frac{\partial \ln p(\mathbf{x};\boldsymbol{\theta})}{\partial \boldsymbol{\theta}} = \frac{\mathbf{H}^T\mathbf{H}}{\sigma^2} \left[(\mathbf{H}^T\mathbf{H})^{-1}\, \mathbf{H}^T\mathbf{x} - \boldsymbol{\theta} \right] \quad (9).$$

Which is exactly in the form of *Eq. (3)*. Hence the MVU estimator of $\boldsymbol{\theta}$ is given by

$$\hat{\boldsymbol{\theta}} = (\mathbf{H}^T\mathbf{H})^{-1}\, \mathbf{H}^T \quad (10).$$

and its covariance matrix is:

$$\mathbf{C}_{\hat{\boldsymbol{\theta}}} = \mathbf{I}^{-1}(\boldsymbol{\theta}) = \sigma^2(\mathbf{H}^T\mathbf{H})^{-1}. \quad (11).$$

The details of reflections on each step is attached in Appendix. Further, [22] provides three examples based on the problem contexts: curve fitting, Fourier analysis, and system identification, before presenting another subsection that extends (1) to a general linear model where the nose is not white. Therefore, it first deals with the whitening approach, and then the above procedure is repeated to develop a new estimator with the same form. In addition, the chapter provides two other practical examples, i.e., on Direct Current (DC) level in colored noise and DC level and exponential in white noise, to assimilate the material on parameter estimation effectively. In the end, there are 14 problems, either signal processing estimation problems or pure mathematics tasks, as [22] calls homework related to basic concepts. To reduce complexity for the learners, the two estimators, one for the white and another for the colored noise, are presented as theorems without rigorous, detailed proofs.

4.2 Impact of Prior knowledge and Understanding of Meaning Making

[24] extended instrumental and relational meaning making of mathematical concepts of [5] to advanced mathematical concepts. Instrumental understanding of a concept refers to the ability to state the definition of the concept, is aware of the important theorems associated with that concept, and can apply those theorems in specific

instances. While a relational understanding includes to understand the informal notion this concept was created to exhibit, why the definition is a rigorous demonstration of this intuitive notion, and why the theorems associated with this concept are true. Looking at the steps from *Eq. (3)* to *(11)*, the textbook provides opportunities for the two different meaning making in light of [24] definitions of understanding. Those who have an instrumental understanding meaning making may remember the rules and procedures applied at each step while those with a relational understanding meaning making can connect the mathematics why those mathematical concepts are working as such: For example, understanding why *Eq. (3)* and *(9)* are connected demands intuitive understanding of the different concept as a basis for constructing a formal argument. In turn, it demands a sold prior knowledge (Huthali, 2014) in the basic mathematical concepts like partial differentiation, which could be a difficult concept for many. In fact, [24] has extended a relational understanding of a concept as somewhat akin to Tall and Vinner's concept image [25]. In this case, the concept image of the partial derivative procedure is a total cognitive structure that is associated with this concept, which includes all the mental pictures and associated properties and processes. As an example, why the partial derivative is employed can be seen as an extension of the experience that when we derivate a function and set up the result to be zero, it is possible to get the extremum values of the function. As we are looking for the minimum variance estimator, it gives a sense of meaning to the learner. Concept image is "built up over the years through experiences of all kinds, changing as the individual meets new stimuli and matures" [25:152], which in turn has huge impact on the meaning making process.

4.3 Impact of Representation and Multimodal on Meaning making

Most parts of the pages of Chapter 4 in [22] are highly dominated by advanced mathematical symbols, very brief texts and few diagrams, no real-life related images. According to [9], different modes like writing, images, mathematical symbols, speech and moving images carry potential for meaning making. The textbook is highly populated with advanced mathematical symbols, which can contribute to the complexity in the meaning making process for learners. In [8] and [26], one finds mathematical competency model connected to mathematical meaning making. One of the elements mathematical competences is dealing with different representations of mathematical entities [26, 27]. In Chapter 4, one finds four types of representations: verbal, symbolic (most dominating ones), diagram (three figures) and context (like system identification, curve fitting, a fading noise, and so on). These four can assist the ability to interpret as well as translate and move between the different representations [27], boosting the meaning making process. However, the dominating advanced mathematical symbols used can be problematic.

5 SUMMARY AND ACKNOWLEDGMENTS

Linear models allow us to model several signal-processing problems in estimation, detection, system identification, pattern recognition, machine learning, etc. It is undoubtedly one of the most critical classes of models that represents a more complex phenomenon in a simplified abstraction. Several service courses in mathematics and statistics cover this content. Meaning making of this model is expected from the students in several engineering problems. The findings show that Chapter 4 of the course material [22] provides different aspects of meaning making in mathematics for engineering students. The linear model-based estimator is presented in a reduced complexity, i.e., without rigorous, detailed proofs that demand a solid prior knowledge of many of the mathematical concepts that are involved. The 18-page chapter is highly dominated by advanced mathematical symbols from different mathematical concepts with higher cognitive demanding tasks and activities, which can increase complexity in the meaning making process by the learner, further reducing the opportunity for learning. Four types of representations (context, verbal, symbol, and graphs), as well as multimodal approaches (writing and mathematical symbols), are used, creating potential for meaning making by the user. However, symbolic representation dominates the pages creating a higher extraneous cognitive load on the learner. Where as examples and contexts contribute for lowering the complexity in the potential for meaning making in engineering students with the mentioned textbook.

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Appendix. Meaning making of the Mathematics related to the MVU estimator for the Linear Model

Equation Number	Explanation of the equation	Mathematical concepts and procedures	Key Words From theory
(1)	$\mathbf{x} = \mathbf{H}\boldsymbol{\theta} + \mathbf{w}$ represents a system of linear equations in a matrix equation of the form. x denote a finite snapshot of a time or space series with dimension N. $\mathbf{H}$ is a matrix of modes with $N \times p$ entries. $\boldsymbol{\theta}$ is a vector of $p \times \mathbf{1}$ vector of parameters to be estimated. $\mathbf{w}$ is a random variable representing noise. It is a $N \times 1$ noise vector with entries represented by Gaussian probability distribution function (PDF).	Linear equations, vectors, matrix, random variable, PDF Estimation	Prior knowledge, mathematical symbols and formalism, modeling
(2)	A probability density function, for the vector $\mathbf{x}$. **It is a** Gaussian function of a normally distributed random variable with expected value **0** vector and covariance **C**.	Exponential function, matrix, inverse and transpose of matrix, product of matrix and vector, Covariance	Prior knowledge, mathematical symbols and formalism, Cognitive load
(3)	The minimum variance unbiased (MVU) estimator , $\hat{\boldsymbol{\theta}} = \mathbf{g}(\boldsymbol{x})$, that fulfils the Cramer-Rao Lower Bound (CRLB) exists if (3) is satisfied. The proof is given in Chapter 3 with 3 pages long involving advanced mathematical concepts like Expectation , integral, partial differential equation(PDE)	Logarithm function, PDF, partial differential equation of a vector, Expectation , integral	Prior knowledge, progress with the content, Understanding
(4)	Applying the PDE on the logarithmic of (2)	PDE and PDF of vector and matrices	Conceptual and procedural knowledge
(5)	Procedure applied to simplify (4). First, the term disappeared since derivative of a constant is zero. The rest is expanded.	Derivation and simplification	mathematical symbols and formalism, procedural knowledge
(6) & (7)	Identities when applying the partial derivatives. It is like the extension of finding the derivative of $(bx)' = b$ and $(ax^2)' = 2ax$.	Partial derivative of a vector and a matrix over vector.	procedural knowledge
(8)	Using the identities in (6) and (7) and applying the PDE in (5). The first term disappears since it is independent of $\boldsymbol{\theta}$.	Partial derivation and simplification	Conceptual and procedural knowledge
(9)	Assuming the matrix $\mathrm{H}^T\mathrm{H}$ as invertible, it is factored out to the front from the expression in (8).	Factorization of a matrix	procedural knowledge
(10)	The MVU linear model-based estimator derived from comparing the expression in (3) and (9).	Comparing expressions	Conceptual and procedural knowledge
(11)	The performance of the estimator in (10) is expressed using the covariance matrix (11), derived from comparing the expression in (3) and (9).	Covariance, Comparing expressions	Understanding, Cognitive demand

PROGRESSION BY IMITATION – EMPIRICAL EVIDENCE FROM NTNU-CERN SCREENING WEEK

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ABSTRACT

Engineering students should work on authentic and 'wicked' challenges to be best prepared for developing technologies that address challenges in our complex world. This can be done with a learning-by-doing approach where students are positioned as entrepreneurs exploring market opportunities for novel technologies. During the NTNU–CERN Screening Week, students in an entrepreneurship program search for and create opportunities based on technologies developed at CERN that may have the potential to later become a start-up. However, the students have limited domain knowledge in terms of the advanced technologies or industrial application of them. Also, the technology readiness level (TRL) of the presented CERN technologies is often far from potential market entry. Previous research has primarily considered how student-oriented programs for technology commercialization are organized. In the present paper, we ask how students proceed to successfully generate market insights

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for progressing in a technology commercialization process. We performed an empirical process study of five student-driven feasibility studies. Our data includes in-depth interviews, field notes and on-site observations. The data is systematically analysed according to the visual mapping protocol for robustness and reliability. Our findings demonstrate how the students are translating an immature technology into a higher TRL and envision applications that do not exist in the real world, to be able to initiate conversations with potential customers and users. These insights contribute to the understanding of how students are becoming 'great pretenders' or 'breaking the norms' to engage stakeholders and enter the ‘Promoters Dilemma’, also challenging existing norms.

1 INTRODUCTION

This study investigates how students generate market insights into novel technologies for progression during their feasibility study. The feasibility study focuses on realizing technological potential and matching technological developments with specific applications and needs (Harris and Harris, 2004). Training students on the market identification of potential use cases of novel technologies is essential for several reasons. First, students could bridge technology novelty and the market by identifying unmet market problems and ways to serve customers' needs (Barr et al., 2009). Secondly, students can be intermediaries between the technology provider and potential market actors (Neck and Liu, 2021, Hellmann, 2007). They provide researchers with essential market insights on potential use cases of novel technologies (Giones et al., 2021) and market acceptance. Third, conducting a feasibility study is also a potential starting point for developing new business ideas and later launching new technology-based ventures (Lahikainen et al., 2022, Neck et al., 2021). A feasibility study also equips students with market knowledge of technology development and a better insight into the innovation process (Klofsten et al., 2020), which is deemed vital for their careers.

Previous research has considered technology commercialization educational programs where students are the main actors in the process (Neck and Liu, 2021). Kaspersen and Aaboen (2021) describe how students are doing feasibility studies on novel technologies developed at the European Organization for Nuclear Research (CERN). The student-driven technology commercialization program is one of CERN’s initiatives for societal contributions from knowledge transfer activities (Nilsen and Anelli, 2016). During the feasibility study, students gain new knowledge of market assessment and ideation simultaneously– obtained through actions and interactions with potential stakeholders (Haneberg, 2020). Thanks to the new insights and interdisciplinary discussion among different actors, students develop ideas of new applications with higher commercial and technology readiness (Markham, 2016). Students, therefore, explore new fields of technological applications – which are potentially overlooked by scientists (Åstebro et al., 2012). However, defining such market needs for novel technologies is challenging because of low level of technology readiness and uncertainty in terms of market acceptance (Stinchcombe, 1965). Moreover, students cannot search all possible technology-market fits due to limited resources (i.e., time) and knowledge domain (Andries et al., 2021).

Nevertheless, the literature has not yet identified how students obtain new insights through engagement with different stakeholders during the feasibility study - given that students have limited adequate social networks and lack professional networks. This study, therefore, focuses on the question “How do students generate market insights of novel technologies during a feasibility study?”. To answer the research question, this paper is structured with an introduction, followed by a conceptual framework of students as imitative entrepreneurs. Using a qualitative approach, the paper then presents findings of how students develop imagined new venture ideas based on market insights and their progression by imitating experts.

The study builds on the theoretical framework of knowledge development through imitation (Meltzoff and Decety, 2003) by offering new insight into how students mimic and pretend to be experts to obtain market insights of novel technologies. The study also contributes to engineering education by offering new insights into teaching approach that emphasizes action-oriented and learning by doing through imitation.

2 THEORETICAL BACKGROUND

To commercialize novel technologies, students – playing a mediating role between the enactors (technology providers) and selectors (technology users) (Bakker and Budde, 2012) – often gather different inputs and feedback from broad stakeholders, potential customers, and users. Students also deal with information asymmetry (Balakrishnan and Koza, 1993) on the "future values" of the novel technologies in the presence of fundamental uncertainty and ambiguity (van Lente et al., 2013). To overcome uncertainty, students search across knowledge domains to identify "connectors" – or people who have experiences and knowledge of the fields they lack (Van de Ven, 2017, Gavetti and Levinthal, 2000). New knowledge is also obtained through interactions and observations (Politis, 2005, Leyden et al., 2014). Given a limited social capital resource, students cannot find relevant people in a short amount of time during their studies. Instead, students get in touch with people they are already familiar with within their network (i.e., through close network search) (Aldrich and Kim, 2007) and apply the snowballing approach to expand their network. To engage with people, students need to explain the novel technologies to different actors using the experimental-experiential process of an iterative process to test market response to the novel technologies and their ideas (Haneberg, 2019).

To envision new applications of novel technologies, students build their "imagined future venture ideas" (Davidsson, 2015, p.683), engaging with stakeholders to attract attention to their ideas. They function as "imitative entrepreneurs" for the diffusion of new technologies (Hannafey, 2003) – which are immature and low in technology readiness level for market entry. During these engagements, students enter the "promoters dilemma" of trying to learn new knowledge to build higher, more mature technology applications while promoting claims based on how their "visions" of the future applications for the technologies. To a certain extent, those claims hinder future technological competencies that do not exist yet in the real world, thus, prompting an ethical dilemma on the real and artificial values of the technologies being promoted. Importantly, students might find themselves in the hype cycle of *"early promises, late disappointment"* – the early stages of novel technology trigger optimistic and exaggerated expectations (van Lente et al., 2013) following a high degree of enthusiasm, excitement, and unambiguity on the real and artificial values of novelty.

Gathering market insights starts with proactively searching and identifying potential market actors, customers, and users to obtain knowledge of the commercial potential. It follows their own assessment and validations of the technology-market fit identification (Andries et al., 2021, Gruber et al., 2013). In doing so, they constantly readjust their choices of market (Gruber et al., 2008) and further develop ideas on new applications of novel technologies – based on the feedback they obtain from external stakeholders. In this case, students pretend that they possess knowledge regarding technology novelty while having limited domain knowledge– imitating experts in the knowledge domain. In doing so, they gather interest and attention from diverse stakeholders in the field (Hannafey, 2003). They keep doing so to an extent that they can initiate conversations and discussions with experts while still grasping new knowledge. To sum up, the process of generating market insights is an iterative and double-loop process of assimilation and acquisition of new knowledge from social interactions, whereas new knowledge is obtained through imitation.

3 METHODOLOGY

3.1 Case selection

We followed a cohort of 39 students in their 1st year of a Venture Creation Programme (VCP) in Norway. The students were members of five student teams. They were introduced to five novel technologies selected based on the following criteria:

- The availability of technology experts
- The novelty and commercial potential for start-ups
- Technology readiness for commercialization

A summary of the process of the NTNU Screen Week is illustrated in Figure 1 below:

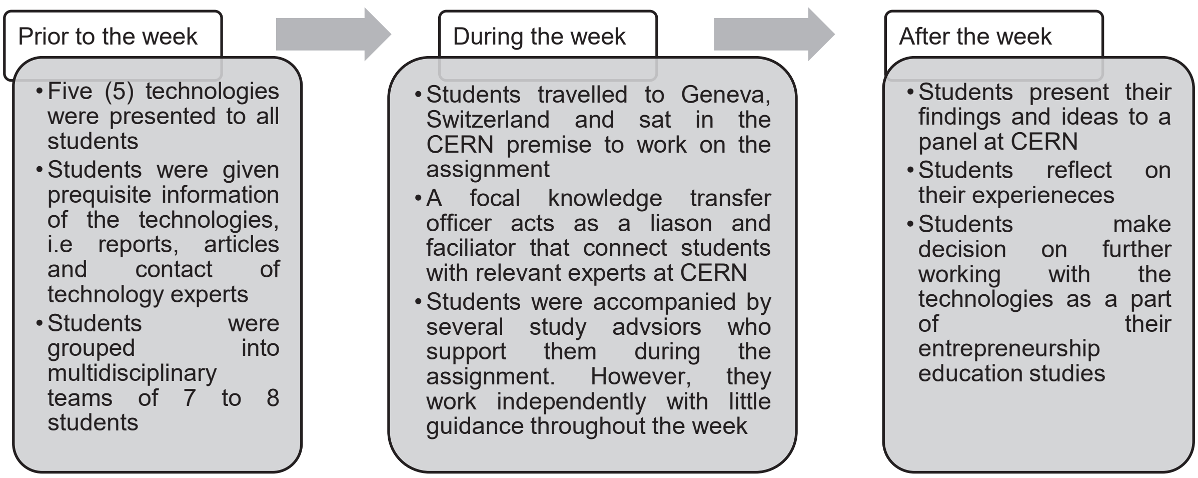

Figure 1: NTNU Screening Week

All the technologies were developed at CERN for fundamental particle physics research; thus, they are considered novel technologies. They require subject-matter knowledge in understanding how they work. In addition, the technologies are generic, far from the market, and in the early stage of commercialization and thus low in terms of technology readiness level (TRL). In addition, the potential technology-market fits are relatively unknown, which deems to be challenging and highly uncertain for students during the feasibility study. The five technologies are included in the Table 1 below.

Table 1: Technologies offered during NTNU Screening Week

Technologies	Team	Technology description
Ultralight Cold plate	UCP	The cooling of power dissipating elements, based on micro-macro vascular pipes embedded in high thermal conductive carbon substrate. It is made of a high thermal conductivity carbon plate, embedding ultralight polyimide cooling pipes

Rucio	RCO	A distributed data management system, which is a system that is designed to access and view a collection of physically separate data storages as one single data storage.
Structured Laser Beam	SLB	A low-cost laser that produces a non-diffractive beam (NDB) that has very low diverge and can maintain the Bessel-like beam and spot sizes for long distances.
Qubik Laser	QLR	A singular light laser developed by CERN and Macquarie University, Australia. It is a simple, efficient, and agile multi-mode to single mode converter in the difficult visible spectrum of 450 nm - 530 nm
White Rabbit	WRT	A fully deterministic ethernet-based network for general purpose data transfer and synchronization. It can synchronize over 1000 nodes with sub-ns accuracy over fibre lengths of up to 10 km

3.2 Data collection

Data was collected through focus-grouped interviews with five students' teams, which utilizes the reflections of the whole team rather than individuals. A total of 70 pages of primary data from interviews and 161 pages of secondary data from students' reports. The primary literature helps us in defining the interview guides. In addition, some reports from previous years and reflections from the university advisors who were actively involved in the process previously have proven are useful reflections on students' behaviours during the feasibility study. To avoid biases and facilitating the process of open discussion, we continued to alter the interview guide with questions (Corbin and Strauss, 2015) as the interview were progressing. The summary of data collection is described in Table 2 below.

Table 2: Data collection

Teams	Primary data	Transcripts of primary data	Secondary data (time log of conversations between each team and external actors)
UCP	2 interviews with each team before and after the week with notes and observations during the week.	12 pages	35 pages
RCO		18 pages	47 pages
SLB		14 pages	24 pages
QLR		12 pages	32 pages
WRT		14 pages	23 pages
Total	**10 interviews**	**70 pages**	**161 pages**

3.3 Data analysis

All transcripts were imported into NVivo software version 10 to conduct inductive thematic analysis through an open coding (Corbin and Strauss, 2015).

First, the sense-making approach was made initially using visual mapping strategy (Langley, 1999) with key anchors of different market insights students gather and from which people that give them those insights, which are drawn from the secondary data as well as interviews. We apply method of critical incidents techniques (CIT) and consider market insights (incidents) as units of analysis (Flanagan, 1954, Bott and Tourish, 2016). We then conducted a within-case analysis (Eisenhardt, 1989) by looking into each team case from both interviews and reports to gain an in-depth understanding of students' processes. A team of four (4) researchers discussed the mapping of this process and illustrated how students make progress throughout the week.

Next, we found patterns among five (5) cases, and labelled them as empirical patterns (Gehman et al., 2018) – which are presented in Figure 2. The use of CIT techniques emphasizes the importance of gathering market insights events in a parallel process of ideas development (Cope and Watts, 2000). Specifically, this method allows us to see how students gather insights and categorize their behaviours during ideation processes. In addition, the visual mapping strategy offer in-depth views on how different processes occur over time.

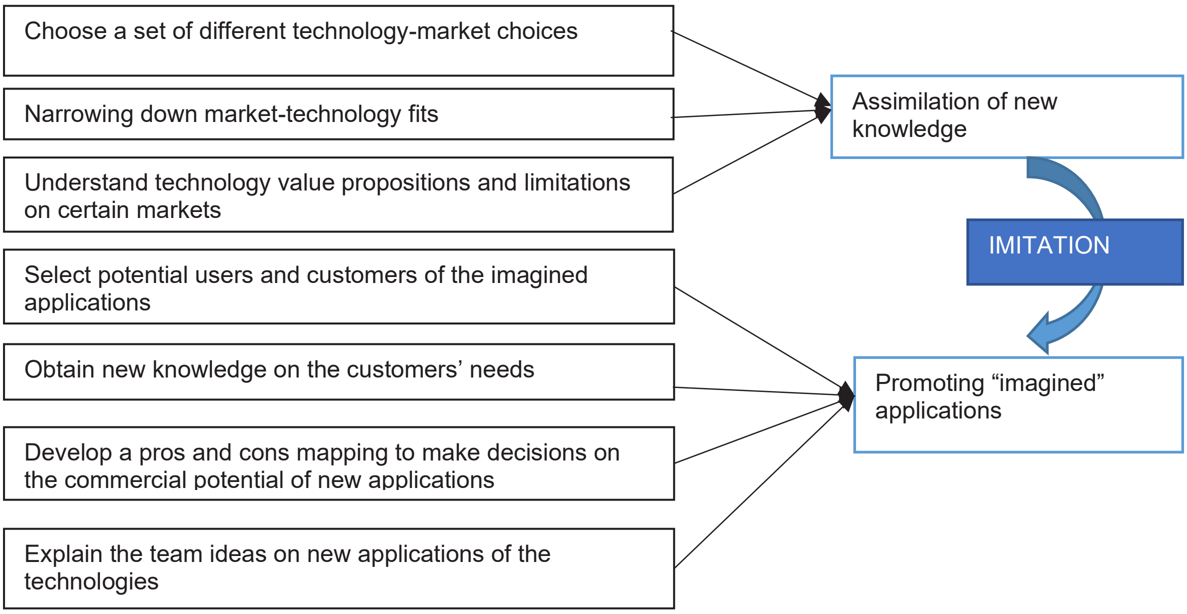

Figure 2: Coding tree structure on the process of gathering market

4 RESULTS

In this section, we present the process of how students generate markets insights of novel technologies and how those insights shape students' progress of technology development. We then discuss on how they make progress of technology development by imitating experts to gain new market insights from other people. We summarize our results with a conceptual framework of progression by imitation (Figure 3).

4.1 The imagination of new venture ideas

Table 3: Markets insights and students' progression during feasibility study

Market insights gathered by students 'teams	Progression in students' idea development	Dimensions
Insights from current technology development	Choose a set of different technology-market choices	Assimilation of new knowledge
Insights from the close network of experts (i.e., professors, alumni students)	Narrow down technology-market fits	
Practical insights on the chosen markets (from market actors)	Understand technology value propositions and limitations on certain markets	
Insights on the whom finds the technologies useful	Select potential users and customers of the imagined applications	Promoting "imagined" applications
Insights on the needs of potential customers	Obtain new knowledge on the customers' needs	
Insights on how realistic the ideas are	Develop a pros and cons mapping to make decisions on the commercial potential of new applications	
Insights on how the market functions	Explain the team ideas on new applications of the technologies	

Table 3 describes the process of the students' teams in developing imagined applications of novel technologies and the critical market insights that support them in developing their ideas. In detail, students' idea development was progressing in parallel with process of gathering different critical market insights. Those insights are, in turn, help students 'teams shape their ideas of technology development and imagined applications of novel technologies. The process of generating market insights starts with students' search process of looking into different market choices for novel technologies. Students are suggested the market applications by experts who work closely with the inventions and possess deep technical knowledge. Students continue to discuss with people in their close network, i.e., alumni students and university professors, and receive some directions on how they should progress further with the cases and relevant actors they should contact. Students use their alertness and their knowledge (Fiet, 2007) to identify new opportunities in the technologies and narrow down the fits between technologies and the markets while conducting both random and "small world search" (Aldrich and Kim, 2007) to obtain new knowledge on the demands and customers' needs.

Assimilation of new knowledge

In detail, students engage in conversations with actors knowledgeable about the field – they try to explain how the technologies work, their limitations, and their unique values. Students establish different market choice sets of how technologies could be applied and assess different markets of novel technologies. To identify those market opportunities, students contact relevant actors in various industries, and they rely on "connection actors" (Zahra and George, 2002) who act as a bridge in introducing students to relevant people offering insights into how the market works and the feasibility of how the technologies could be implemented into one market. These connections could be researchers, technology experts, market actors, etc. As the feasibility study is conducted in an educational context, the primary relationship that introduces students to new knowledge fields are researchers at research institutions.

> *"Researchers. We made our thoughts on how you can fit this product into other markets, but we just mainly talk to researchers."*

The assimilation of new knowledge is the process of students learning different understandings related to the technologies, markets, and constantly absorbing new knowledge. The validation of different market sets could heavily rely on their ability to know "which information to search" and "whom to search" based on the team's knowledge of the technologies.

> *"So now you can take your time getting some thoughts on who you should ask and what you should ask them. So maybe ten people you call will give more valuable information than a hundred. So, it's part of the learning process."*

Promoting "imaged" applications

Students develop new ideas for market applications from novel technologies based on the external responses of different actors and the internal team discussion. This is an iterative process based on their ability to understand the technology and identify relevant and important market actors.

> *"It's very iterative, a combination of luck and routine."*

“You sort of need to connect the dots between technology and how this can be transferred for our idea and business model. That can be very difficult, I think, especially in the beginning, you just ask these open questions, and you don't get deep enough to get some value out of the questions. But now I feel that it's more quality over quantity now than in the beginning.”

Students could identify several relevant market actors who show interest and offer insights into the potential application fields. They could be able to narrow down the market and continue to find essential actors who offer how the technology could be developed further.

“We understood that in this market, weight is extremely important. And the weight of the ultra-light cooling plates is ultra-light. And we also understood that cooling is a big issue in that market. Sometimes people have to turn the satellites completely off to cool them down. And we thought that if the plates of the cooling systems can be light, that will be great for that market”

In the context of technology novelty when the market does not yet exist, students engage in conversations to promote their ideas while having limited knowledge of technology probe two main challenges. On the one hand, students quickly build up their competencies regarding the technology and can obtain new knowledge quickly. On the other hand, students might potentially enter a “promoter dilemma” while promoting their ideas. In particulate, this dilemma refers to the claims being promoted about their ideas and how realistic they are. Especially in the context of novel technology, students might enter a hype cycle of high expectations at the early phase of technology development.

“Maybe kind of like persuasion for other people to accept your ideas if you're going to be a supplier to Equinor, you have to have some history of making them trust and ability to provide credibility to go forward with this project.”

4.2 Progression by imitation

Infants often mimic adults in their behaviours – which constructs deep into our cognition (Meltzoff and Decety, 2003). Students engage in conversations with actors knowledgeable about the field – they try to explain how the technologies work, their limitations, and their unique values. While students might not be fully aware of the technical specifications, they obtain a certain knowledge base that builds up their confidence. They also mimic actors they engage with, explaining the technology in such an attractive way to gather feedback from potential users and customers.

“I've come to the place where I build up such competence that I can at least ask the relevant and critical questions, I think. There's always a way to go until you're an expert on the laser.”

The imitation phase starts when students have talked with many customers, and they can see the potential problems, challenges, and needs from specific markets – they could use those patterns to further engage in a deep conversation and follow up as they are becoming knowledgeable about the field. Those patterns could be the language that these actors use, the kind of conversations or topics that might interest them, and the ability to understand and follow up on discussions. Gathering market feedback is used either (i) to validate the information students would like to test out – how feasible their ideas are or (ii) to obtain attraction on how likely their ideas are accepted.

"I think it's really important to talk to many people so that you know the pattern of how they're thinking. And then you can respond and ask questions back, and you can also predict which questions they will ask because you've talked to many, so you know how they're thinking."

In summary, we develop a conceptual framework of students' progression by imitation (Figure 3). Students make progress through the assimilation of new knowledge. To promote their ideas to potential customers and obtain new knowledge simultaneously, students pretend they are subject experts in the "imagined" applications of novel technologies to attract feedback and attentions from a wide range of stakeholders. In return, those feedbacks also support students in gaining new knowledge through an iterative, double-loop process of imitation.

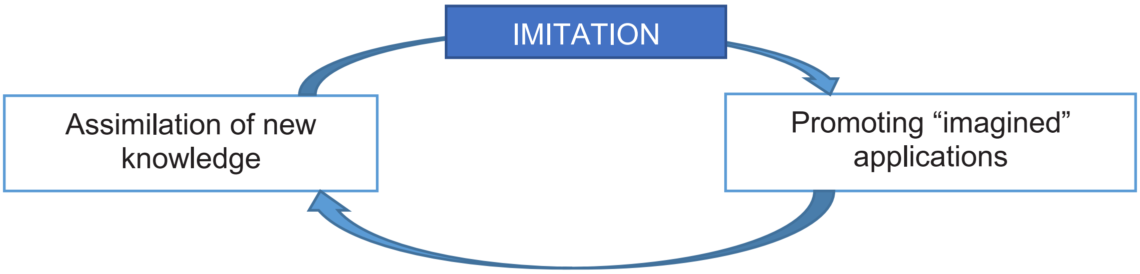

Figure 3: Progression by imitation

5 LIMITATIONS

One of the main limitations in this study is the timespan which the study was conducted during the NTNU-CERN Screening Week. Although this allowed us to have an in-depth analysis into how students make progression, we consider a longer longitudinal data collection in the future. It is more insightful for the understanding of how students interact with external actors to collect market insights. Another limitation is the process of visual mapping of students' ideation were done through researchers' interpretation instead of students themselves. We also propose a further study to investigate further on the imitation learning approach, especially the characteristics of this approach among students acting entrepreneurial. Another further study could also about how imitation influences the development of students' entrepreneurial ideas and future venture creation progress.

6 SUMMARY AND ACKNOWLEDGMENTS

In this paper, we explore how students generate market insights of novel technologies during a feasibility study. We identify two main steps which students link through imitation to progress their process – the assimilation of knowledge and promotion of imagined applications of the technology in focus. Our findings show that students use the initial insights to develop an idea of the application of the technology, gather feedback from the market by presenting the potential use of the technology as it is user-ready before the feedback is used to develop new insights about the potential use of the technology.

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A LOOK AT VOCATIONAL AND ACADEMIC STUDENT BACKGROUNDS IN ABILITY TO SOLVE PRACTICAL PROBLEMS

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Conference Key Areas: Equality Diversity and Inclusion in Engineering Education, Recruitment and Retention of Engineering Students

***Keywords**: Problem Solving, Vocational Education, Student Outcomes*

ABSTRACT

While most students in the UK will enter engineering degrees with traditional academic qualifications, a significant proportion will come from backgrounds which use vocational based qualifications to gain entry to degree level study. Indicators show that students from lower socio-economic backgrounds are more likely to be among those using vocational qualifications to gain entry to University and may not progress as well. This is often linked to difficulties in traditional academic elements of the degree such as mathematics where both the content and learning approaches are much less familiar to students with a vocational background. These academic skills are not the only skillset needed of a graduate engineer and to look at ability in practical problem solving a trial was devised.

Students in their first year of a range of engineering degree programmes were recruited from a number of disciplines including those on mechanical, electrical and chemical engineering degrees and having entered those degrees from a range of educational backgrounds.

Students were paired up to work on a series of short problem solving exercises designed to require an element of logical and creative thought of the type needed in

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engineering problem solving but were such that no specific technical knowledge was needed. Work was videoed and then encoded to help with analysis.

The work, while from a small sample size, appeared to illustrate that students on engineering programmes want to solve problems and capability appeared to be independent of educational background suggesting this skill may be lost to society if engineering students from vocational backgrounds drop out early due to struggles with more academic topics.

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1 INTRODUCTION

1.1 Pre-university Study Routes and Outcomes

While many countries will have a “normal” entry route for entry onto university level degree programmes, there are often quite significant alternative routes, particularly for those types of degree, including engineering, which lead to a vocational career path.

Within the English and Welsh context, entry to university is typically based around student performance on high school leaving qualifications known as A-levels lasting two years from when students are 16. Students will commonly take three A-levels in classic academic disciplines such as Mathematics, Physics, History etc. Each degree programme at each university will then have an entry tariff based on an appropriate mix and grade in these qualifications (eg. BBC to include grade B in Maths and a Physical Science or Technology subject).

At age 16 however students with weaker academic performance may find routes to A-levels closed and may move onto a vocational stream, though others may choose this even if qualified for the A-level option. This stream leads to an applied qualification, typically an award known as a BTEC, though this has recently replaced by the newer T-level qualification. The newer qualification features 45 days industry placement as part of the training but carries forward much of the BTEC approach and aims at a similar market [1]. A single BTEC or T-level is built around the skills needed broadly for entry into a career of further study in a vocational field, such as engineering, agriculture, construction or catering and is nominally equivalent to three A-levels. As such these qualifications are also often used as a route into a University degree or apprenticeship.

Experience has however shown that students from vocational routes have often struggled adapting to university study with higher drop-out rates and final outcomes [2-4].

1.2 Research Question

It should be stated that the reasons for the poorer performance of vocational students once on their degrees has been attributed to a range of factors. These include the students’ background – a higher proportion will come from lower socio-economic groups with less family history of high education [5,6] and the nature of the qualification – often having few exams but more coursework, leaving a study skills gap. For engineering students there are often particular issues around mathematics elements of degrees [7] however the gap between vocational and academic entry qualifications is sector wide [8-10].

Ultimately however engineering is a vocational discipline aiming to provide workable and effective solutions to technical challenges. Underpinning academic knowledge can support this but is not always the key to effective and pragmatic problem solving.

This work therefore looked at the problem solving skills of a range of students coming into University engineering degrees to help answer the question "Does pre-degree academic background influence problem solving ability?"

2 METHODOLOGY

2.1 Participants

Students were invited to take part from cohorts on the first semester of engineering degrees at an English university. These students were targeted to ensure the investigations were largely focussed on assessing the problem solving skills brought by the students into the degree from their different backgrounds rather than those developed during the degree. A modest "thank-you" shopping voucher was provided to participants in recognition of their involvement. Selection of candidates and the overall methodology went through the ethics process of Aston University (ref.1550).

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2.2 Problems Set

The problems set were mixed to explore different challenges. Some relied on logic and a process of honing in on a specific answer, others involved geometry and shape fitting with others were more open ended asking for ideas for devices or approaches to solve practical problems.

Fig 1. Still excerpt from student problem solving videos

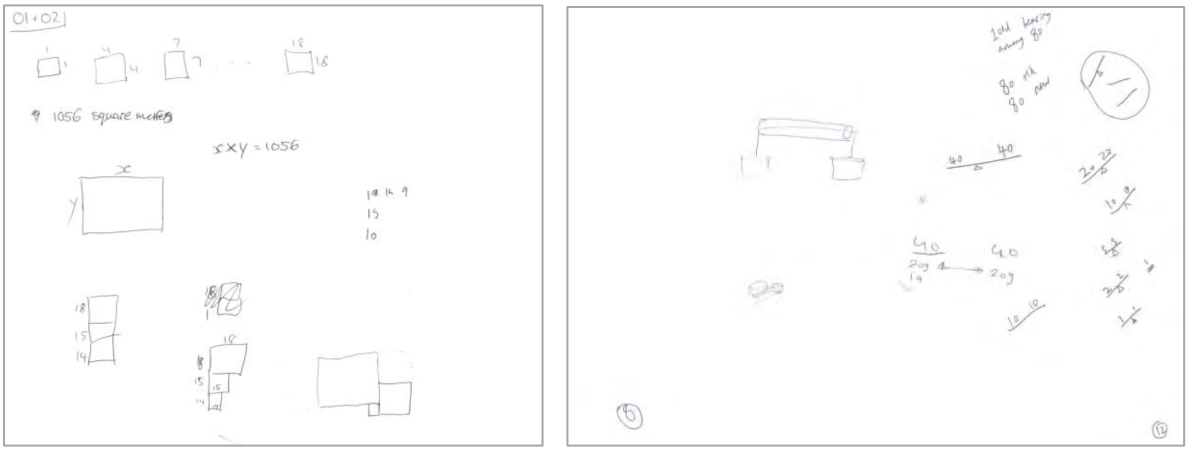


Fig 2. Student note sheets

Exemplar Trial Record Following Transcription and Coding

Date : 26.01.22
Location : L36
Problem set : Ball Bearings
Participants : 5,6

Time		Code	Tool	Notes
03:42:32				Problem set
03:42:46	00:00:14	EXP		Solution proposed (5)
03:43:19	00:00:33	QUE		Is that method slow...
03:46:05	00:02:46	ADA		Try to optimise process
03:46:20	00:00:15	PRS		Yes that's it its legit, man we're so smart, its why we do engineering bro!
03:52:00	00:05:40	PAUSE		
03:53:24	00:01:24	QUE		Realise (diricred that there is an error)
03:54:43	00:01:19	ABA		Try to think of indirect solution despite being on the right lines.
03:56:00	00:01:17			Time limited - problem abandoned.

Exemplar Trial Record Following Transcription and Coding

Date : 26.01.22
Location : LG36
Problem set : Logic You Tube
Participants : 14,16
File : C:\Users\thomsoga\Desktop\Trial Data\220126-14-16\SUNP007

Time		Code	Tool	Notes
14:34:03				Info released
14:34:36		CLR	paper	14 notes down key info "I am literally writing it !"
14:35:00		PRG	paper	16 formally writing down variables
14:37:58		TRI		Debating different ideas - could also be...
14:39:30		QUE		Questioning - trying to eliminate options ?
14:40:23		TRI		Following a semi logical path, gradually eliminating and confirming data
14:42:00		PRE		Finished ?

Fig 3 : Encoded data from student trials

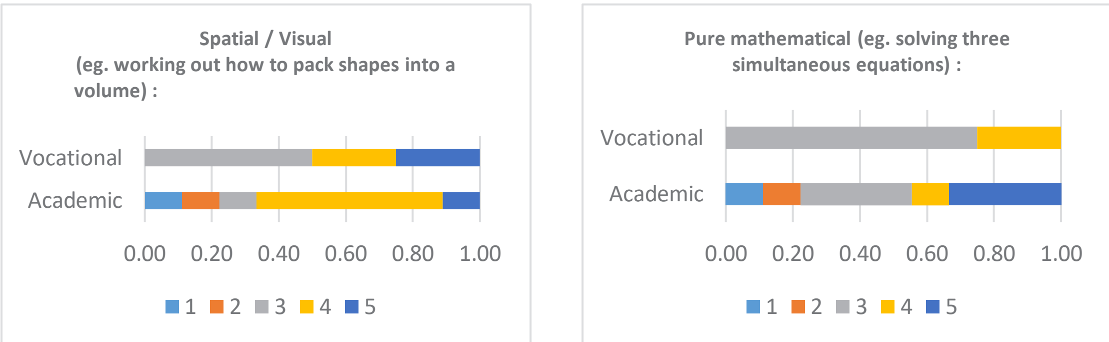
2.3 Protocol

Students were initially asked to complete a questionnaire covering some background demographics together with a self-appraisal of confidence levels and preferences in terms of problem solving. Students were paired up to carry out problem solving with the pairing designed to encourage a dialogue which would draw out the problem solving strategies and approaches. The problems set were varied but did not require specific engineering knowledge as the students were all new entrants to a degree and the focus was on solution finding approaches rather than any underpinning factual knowledge. Basic (non-calculus) maths skills were however expected. Students were allowed to use a calculator if needed and were provided with blank paper to help sketch out and communicate their thoughts. To provide a record of the work students were videoed solving the problems (Fig 1) and the sketches and written workings were retained (Fig 2). Data was then encoded for analysis and review (Fig 3).

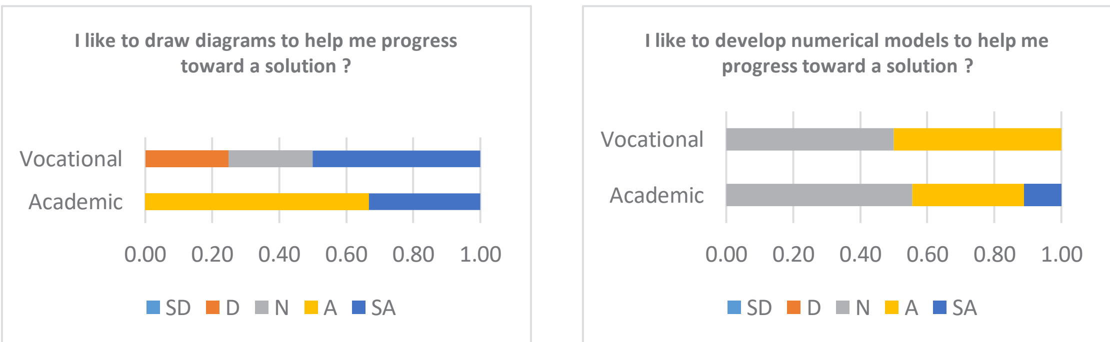
3 RESULTS AND DISCUSSIONS

3.1 Questionnaire

Students were asked a range of questions in the questionnaire related to demographics, confidence levels in solving different problem types and preferred approaches in solving problems. Figure 4 shows outputs from some of these questions.



(a) Student confidence levels for different problem types (1-low, 5-high)



(b) Student problem solving approaches (Strongly disagree (SD) > Strongly agree (SA))

Fig. 4 : Sample data from student questionnaires grouped by entry qualification type

While there are some differences in preferences and confidence levels between the students who entered via a traditional academic route and those who arrived using other qualifications, the limited numbers of participants limit the extent to which the data can be considered statistically robust.

For the practical tests, performances were relatively similar between the two groups of students.

Most students were able to complete the logic type problems in a similar manner. These problems had a set of incomplete data together with statements which, if applied logically, could complete the missing data. Most student pairings were able to complete these satisfactorily. Tables were commonly used to identify the given, resolved and missing data with a semi-systematic approach to identifying the missing results.

Similarly both groups embraced some of the more open ended challenges, such as proposing design ideas for a tool to help plant seeds precisely or another to extract small objects from childrens' ears and noses. An iterative approach was used and these new students, while early in their evolution as engineers and lacking formal training often brought in personal experience to inform the process. Iterative and sharing processes involving validations, additions and improvements were also common. Surprisingly, given the goal and the brief, the use of drawing and sketching to explain or develop ideas was far less common.

The use of physical aids to help in the problem solving was also explored via a tile fitting problem. Students were tasked with determining the size of rectangle which could be constructed from a set of square tiles (*Fig 5*). At the start of the problem the tiles were merely listed and not presented physically. It is however relatively straightforward to determine the rectangle size as the overall area of the tiles is known and only certain combinations of rectangle geometries would fit with the tiles provided. Only one student pairing however achieved this and most relied on sketching possible layouts to aid their thinking and then using the later supply of physical tiles to solve the problem (*Fig 6 & 7*). There was no notable difference in approach between those students from academic or non-academic entry routes.

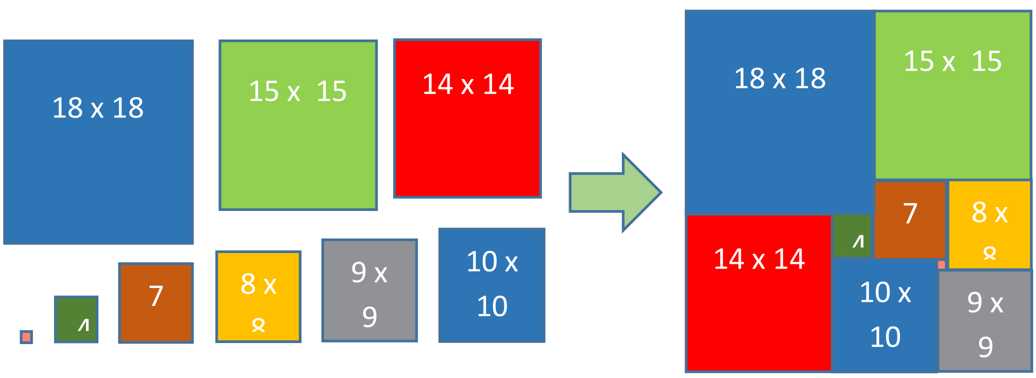


Fig 5 : Tile fitting problem (with solution)

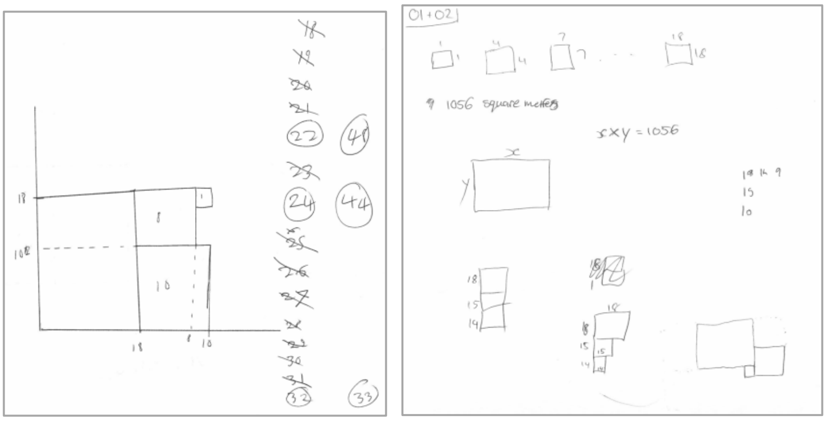


Fig 6 : Student Working Papers For Tiling Problem.

Fig 7 : students using physical paper tiles to solve the tiling problem

4 SUMMARY AND ACKNOWLEDGMENTS

4.1 Summary and future work

The work here indicated that the core problem solving ability of students appears very similar whether they entered university with a background centred on academic or vocational qualifications.

The robustness of these outcomes are not as strong as would be hoped due to the small sample sizes (n=20) and difficulty in recruiting participants. It is hoped to re-run a similar trial in future using the same protocol to bolster the underlying dataset.

None the less if we believe problem solving to be the core of professional engineering practice to lose students from vocational backgrounds with sound fundamental skills in finding solution can not be a sound long term option.

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STUDENT PERSPECTIVES ON SUSTAINABILITY IN ENGINEERING EDUCATION: MULTIPLE CASE STUDY OF EUROPEAN BACHELOR'S PROGRAMS IN INDUSTRIAL ENGINEERING AND MANAGEMENT

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ABSTRACT

The global sustainability crisis is calling for engineers to take action. To enable and empower engineers to address this crisis, there must be a change in engineering education. Given the industry's key role in not only causing but also solving this sustainability crisis, it is especially crucial to improve how sustainability is addressed in industrial engineering and management (IEM) education. This paper examines (1) to which extent European IEM degrees are covering sustainability; (2) European IEM students' motivations to learn and work with sustainability topics; and (3) their perceptions of their degree's contribution to their knowledge and motivation regarding sustainability; and (4) which sustainability-related changes they would like to see in their degrees. Three IEM curricula covering different regions of Europe—Portugal, Germany, and Turkey—were analysed. The mixed-method analysis included a quantitative evaluation of the extent to which each course meets specific theory-based learning objectives pertinent to sustainability in engineering education. The analysis was complemented by students' perspectives, which were gathered through group discussions and interviews. The results reveal how sustainability is addressed in IEM education in different European regions, its impact on students' knowledge and motivation for sustainability issues, and how sustainability in engineering education should be developed based on students' perceptions. These findings contribute to the research on sustainability in engineering education and support university teachers in revising engineering study programs to provide adequate sustainability understanding and skills to students.

1 INTRODUCTION

As technological solutions and innovations are considered key to addressing the ongoing sustainability crisis, engineers play an important role in solving this crisis (Fitzpatrick 2017, 916–926; Pritchard and Baillie 2006, 555-565). However, Engineering Education in Europe has traditionally prioritised technical skills and knowledge, often neglecting the social, economic, and environmental dimensions of sustainability. To equip and motivate future engineers with the necessary knowledge and skills to design and implement sustainable solutions that can contribute to solving this crisis, a rethinking of the engineering curriculum and pedagogy is required.

To form a comprehensive big picture of the current state of sustainability in engineering education and complement the lacking extant research, it's important to consider multiple perspectives, including those of students, "whose capabilities and characteristics affect the reception of new views and are at the core in terms of achieving the sustainability goals" (Bask 2020). Given the industry's key role in the sustainability crisis, it is particularly relevant to improve how sustainability is addressed in industrial engineering and management (IEM) education. Thus, this research aims to provide engineering educators, particularly in IEM, insights into the development needs of the current curricula, based on the perspectives of IEM students at European Universities, enabling a pathway for more sustainability-oriented education of future engineers.

Stemming from the above-mentioned gaps, this paper aims to answer the following research questions: (1) to which extent European IEM degrees are covering sustainability; (2) European IEM students' motivations to learn and work with sustainability topics; and (3) their perceptions of their degree's contribution to their knowledge and motivation regarding sustainability; and (4) which sustainability-related changes they would like to see in their degrees.

The paper is structured as follows. In section 2, we briefly discuss the theoretical background and extant research gaps on sustainability in engineering education and its educational learning objectives. In section 3, we explain our methodological choices, i.e., how the mixed-method multiple case study of three IEM bachelor's programs in European universities was conducted. In section 4, the findings are discussed, and their contributions to research and practice are concluded in section 5; the findings will contribute to the research on sustainability in engineering education, and support university teachers in revising engineering study programs to provide adequate sustainability understanding and skills to students.

2 THEORETICAL BACKGROUND

Prior research on sustainability in engineering education has been interested in sustainability awareness (Azapagic, Perdan, and Shallcross 2005, 1-19), but has often centered on environmental sustainability, neglecting social and economic sustainability (Thürer et al., 2018). To educate engineers with the necessary sustainability-related skills, we need a more holistic view of the sustainability dimensions, extending beyond the environmental side of sustainability (Thürer et al. 2018, 608–617). Economic and social levers are critical in engineering; "so that changes in economic and social behaviours can complement and facilitate technological change" in moving humanity towards sustainability (Fitzpatrick 2017, 916–926). Therefore, this paper focuses on the improvement of how sustainability, in all its environmental, social, and economic components, is addressed in engineering education.

Research has recently grown to address the need for sustainability education in engineering fields such as chemical and environmental engineering (Azapagic, Perdan, and Shallcross 2005, 1-19; Glavič, Lukman, and Lozano 2009, 47-61). However, research focusing on the IEM field lacks comprehensive understanding. IEM reflects a mix of more traditional engineering studies, such as physical sciences, mathematics, manufacturing, but also social sciences as well as management, human factors, and business studies (Elsayed 1999, 415–421). Hence, the IEM perspective has a high potential to impact the implementation of sustainability practices in the industry.

We approach the research gaps by adopting the educational objectives for Engineering for Sustainable Development (ESD; Quadrado 2013). According to Quadrado (2013), sustainable development is pursued through education by: (i) developing student awareness of issues in areas of sustainable development; (ii) exploring and demonstrating the role and impacts of various aspects of engineering (technology, design, process, materials, etc.) and policy decisions on environmental, societal and economic problems; and (iii) equipping students with engineering and decision-making tools and methodologies and providing them opportunities to apply them on issues related to sustainable development. These objectives were used as the foundation to establish a research framework for analysing sustainability in engineering degrees, which is further explained in the next section.

3 METHODOLOGY

We apply a multiple case study of three carefully selected IEM study programs across European universities. Each of the cases was analysed by a local student to allow a full understanding of the case context. We employed a mixed-methods approach, which allows the investigation of particular educational phenomena with great depth and breadth (Almalki 2016, 288-296), hence permitting us a comprehensive understanding of the curricula and their ESD coverage, while also gathering valuable qualitative insights from local students and graduates.

The research process unfolded in four steps. In the first step, we sampled a range of curricula cases to represent different regions in Europe. During the case sampling, we chose IEM study programs that would assist us in taking into account the contextual and geographical diversity within Europe, as well as convenience sampling (Etikan, Musa, and Alkassim 2016, 1-4). The selection resulted in having one case study program from each of the following Universities: Bilkent University (Ankara, Turkey), University of Porto (Porto, Portugal), and Technical University of Kaiserslautern (Kaiserslautern, Germany).

To address particularly research question 1, a quantitative analysis was performed in the second step to evaluate the degree to which each course followed the objectives of engineering for sustainable development as outlined by Quadrado (2013). The courses were rated on an integer scale ranging from 0 (objective not addressed) to 3 (objective fully addressed). The primary data source for this step was the course descriptions in the Universities' course catalogs. When the available data was perceived insufficient, we sourced secondary data from students who took the course recently and/or professors of the respective courses.

In the third step, we shifted to the qualitative part of our research to further explore the students' perceptions on sustainability in IEM curricula. We organized three workshops to engage with local students and recent graduates to gather their input and perspectives on the case curriculum they are/were studying and how it addresses sustainability (one per University). During the workshops, the students were asked to rate themselves on a 10-step Likert scale, to self-evaluate how much they agreed or disagreed with 13 statements. Follow-up discussions, and open-ended questions related to research question 4, were initiated to profoundly understand students' viewpoints, and workshop memos written. The presented statements aimed to gather insights mainly to the research questions 2 and 3, and covered topics such as students' motivation to learn about sustainability and pursue a career in this field, and how students perceive the contribution of their degree to their knowledge and motivation regarding sustainability. A total of 18 students participated voluntarily, without external incentives, in the workshops, with 7 students from the University of Porto, 7 students from the Technical University of Kaiserslautern, and 4 students from Bilkent University. In the final and fourth step, the findings from the within-case analysis were compared in cross-case analysis to detect relevant differences and similarities between the cases.

The research quality was ensured with multiple tactics, such as data and researcher triangulation.

4 RESULTS

4.1 Degrees' profiles and sustainability coverage

Bilkent University (Turkey)
Bilkent University's chosen Bachelor program is named "Industrial Engineering", or, in Turkish, "*Endüstri Mühendisliği*", coordinated by the Industrial Engineering Department. In 2019, a curriculum revision resulted in new energy and sustainability-related elective courses. The range of elective options, and senior projects, in which students concentrate on issues facing businesses today, are considered the curriculum's differentiators. Additionally, renewable energy and sustainability have recently become prominent in graduation projects.

Technical University of Kaiserslautern (Germany)
For the Technical University of Kaiserslautern, the IEM Bachelor programme with a focus on civil engineering, named officially "*Betriebswirtschaftslehre mit technischer Qualifikation im Bauingenieurwesen*", which translated to "Business Studies with technical qualification in civil engineering", will be analysed in this paper. The main department responsible for the IEM programmes is the economics department. In 2021's curriculum revision, the only mandatory sustainability course was deleted, and 2 elective courses were introduced, but sustainability has nevertheless gained general traction in education.

University of Porto (Portugal)

The "Bachelor in Industrial Engineering and Management", or, as officially named, "*Licenciatura em Engenharia e Gestão Industrial*" is the degree analysed from the University of Porto. This degree has a strong focus on Mechanical Engineering, doesn't offer any specialisations, and the elective courses are very limited. The degree coordination is under the Department of IEM. In 2021, the University of Porto's IEM program separated the existing integrated master's program into a bachelor's and master's program, but no changes were introduced regarding how sustainability is approached. Currently, teachers incorporate specific sustainability-related themes into their courses' curriculum on their own; however, there aren't any standards or criteria for doing so.

These 3 degrees were analysed based on the extent to which each of their courses covers each of the educational objectives for ESD, as explained in the methodology section. The results of this analysis are presented in Table 1, in percentage to ease comparison.

Table 1. Quantitative analysis of the coverage of ESD objectives in the selected case IEM degrees

	Objective	Development of student awareness of issues in areas of sustainable development				Exploration and demonstration of the role and impacts of various aspects of engineering and policy decisions on environmental, societal, and economic problems				Equipping students with engineering and decision-making tools and methodologies and providing them opportunities to apply them on issues related to sustainable development.				
	Rate	0	1	2	3	0	1	2	3	0	1	2	3	Total courses
Bilkent	Mandatory	69%	25%	3%	3%	66%	22%	9%	3%	75%	16%	6%	3%	32
	Elective	62%	33%	0%	5%	62%	24%	10%	5%	62%	19%	14%	5%	21
Kaiserslautern	Mandatory	65%	18%	18%	0%	71%	24%	6%	0%	71%	24%	6%	0%	17
	Elective	75%	6%	6%	13%	75%	6%	6%	13%	75%	6%	6%	13%	16
Porto	Mandatory	60%	33%	7%	0%	63%	27%	10%	0%	67%	20%	13%	0%	30
	Elective	78%	0%	11%	11%	78%	0%	11%	11%	56%	22%	11%	11%	9

It is apparent that the ESD objectives are barely addressed in the case degrees. Still, Kaiserslautern appears to meet these objectives to a slightly greater extent than the other degrees. We can also observe that the objectives are slightly more addressed in elective courses rather than mandatory ones.

4.2 Students' motivation to learn about sustainability and pursue a sustainability-related career at the beginning of their professional lives

According to the findings, students across all three universities display a strong motivation to learn about sustainability, with Bilkent students being the most motivated (scores 8-10). These students perceive sustainability to be an increasingly important topic in their future personal and professional lives.

Students' motivation to contribute to addressing sustainability and prioritizing companies with sustainability commitments at the beginning of their careers was rated similarly among students from the same university. Bilkent and Kaiserslautern students demonstrated a positive inclination towards both topics, while most Porto students had negative scores. Bilkent students are motivated to work on sustainability issues because they associate it with working for a reputable company, which they believe is more likely to have established sustainability commitments and provide higher earnings. Conversely, Kaiserslautern students had varying levels of motivation, as some perceived sustainability as a top priority, while others viewed it only as a desirable attribute. The variation seemed to stem partly from the different awareness levels in their earlier educational path. Most Porto students choose to prioritize personal financial well-being over sustainability in their entry-level positions. They believe that they can have a greater impact on sustainability as citizens rather than in their first jobs and perceive obtaining a first job with a sustainability focus as extremely challenging.

Bilkent students expressed high levels of confidence in working with sustainability topics after graduation, scoring a 7. This result was mostly influenced by the fact that one professor was promoting his/her sustainability-related work project in a class. Kaiserslautern students, however, scored lower (between 4 and 5), due to a lack of confidence related to all career paths, which they believe is a result of a strongly theoretically-based education. In Porto, the students who scored lower (between 4 and 5) tended to be females and mentioned that sustainability was not given sufficient emphasis in Porto’s courses, often being addressed solely as an afterthought. Contrarily, students with higher scores (between 8 and 9) stated that the degree prepares them for any career, including sustainability-related ones.

4.3 Students’ perspectives on the contribution of their degree to their motivation and knowledge regarding sustainability

Although students’ motivation to learn about sustainability is high, the scores were generally low for the extent to which their courses contributed to their motivation (1-4). Kaiserslautern students considered their courses to motivate them slightly more than the other universities thanks to a sustainability course, which used to be mandatory but is now elective since 2021. One student scored a 9 due to choosing a sustainability-oriented thesis topic.

The students' self-perceived level of general knowledge on sustainability is moderate (majority between 5-6). In Porto, the younger students had lower scores (1-4). On the other hand, when asked about their level of IEM-related sustainability knowledge, most students, regardless of their university, rated themselves with significantly lower scores (1-2). Meanwhile, older students scored slightly higher, indicating that their accumulated time in university studies equips them with more knowledge, whether it’s generated at the university or outside of it.

The students’ perceptions of whether their degrees equipped them with relevant knowledge and skills to work on sustainability projects in the future varied. Bilkent students believed that the courses focused on developing general soft skills rather than sustainability. Kaiserslautern students agreed that the updated degree did not guarantee relevant sustainability knowledge and offered professional sustainability skills to a varying extent (scores varying from 1 to 6). The variation can be explained by the different technical backgrounds of the students. Porto students highly disagreed that their curriculum ensured relevant knowledge on sustainability, with mixed opinions on relevant skills. Gender differences were noted here, with mostly men scoring higher and claiming that the degree prepared them for any activity related to the IEM field, including those involving sustainability, while others believed that despite the degree's broad scope, it did not provide them with the necessary skills to address sustainability issues.

The majority of students agreed that they have the need to seek additional resources to acquire relevant knowledge for sustainability-related projects (scores ranging from 6 to 9). However, when asked about the need to seek additional resources to acquire relevant skills, the answers were more varied. Bilkent students expressed an even greater need for external resources for developing relevant skills. In contrast, Kaiserslautern and Porto students provided a wide range of responses, with some stating that their degree already equipped them with general skills that could be applied to sustainability-related work, while others argued that more specific skills were necessary and not being provided, hence the need to turn to external sources.

Most students had low or no expectations at all towards their curricula addressing sustainability when they started the selected bachelor, with the exception of a few students from Porto who had higher expectations due to their higher exposure to sustainability in some of their extracurricular activities during high school.

Finally, the majority of students across all universities expressed dissatisfaction with the current level of sustainability integration and desired more incorporation of sustainability in their courses. Yet, a few students from Porto were satisfied with their degrees as such, saying that although their degree program did not have a significant emphasis on sustainability, it provided them with adaptable skills to handle diverse situations.

4.4 Desired changes in IEM sustainability education from students

Students expressed a general desire for greater emphasis on sustainability throughout their degrees. To achieve this, the students suggested incorporating sustainability into more courses, creating new courses that specifically address sustainability, and offering project-based opportunities to apply sustainability-related knowledge. The students from Kaiserslautern recommended that at least one mandatory course be dedicated to sustainability, while those from Porto mentioned that such a course could cover potential sustainability careers. Finally, the students from Porto suggested inviting guest speakers for lectures to help achieve these goals.

5 CONCLUSIONS

Our findings contribute to the research and practice on sustainability in engineering education by showing that sustainability is still poorly addressed in European IEM degrees despite the region. Despite this, students are generally motivated to learn about sustainability and contribute to addressing sustainability challenges in their future careers, although this is not seen as a priority for everyone and is perceived differently depending on students' views on sustainability work in their countries. The courses' contribution to students' sustainability knowledge is perceived as very low, while the contribution to developing relevant skills to work on sustainability projects varies among students. Most students feel the need to resort to external sources to learn about sustainability, but not necessarily to develop skills. Despite not having high expectations towards sustainability when they started their studies, students express dissatisfaction with the extent to which sustainability is being addressed in their degrees. Students suggest, for example, higher incorporation of sustainability in all courses and the implementation of courses in different formats.

These insights contribute to research by providing a new understanding of the state and directions for integrating sustainability into engineering education in Europe, not only from an environmental sustainability perspective but holistically (Thürer et al. 2018, 608–617), targeting particularly industrial engineering and management (Elsayed 1999, 415-421) educators. Meanwhile, the research provides practical contributions for the teachers in engineering education: our findings can support professors in the attempt to design more sustainability-oriented curricula by providing professors with relevant insights on their students' perspectives.

Even though just three degrees have been studied and a limited number of students participated, this study is an important early step into exploring sustainability in engineering education, and made it possible to identify some interesting perspectives that can serve as a basis for further investigation. An intriguing finding is the contrasting views that Turkish and Portuguese students have on the financial rewards of sustainability-related work, as Portuguese students express not wanting to prioritize companies with big sustainability commitments at the beginning of their careers due to the importance they place on earning a higher salary, whereas Turkish students associate working on sustainability issues with working for a reputable company and earning a higher salary. Another intriguing observation is the students' dissatisfaction with the insufficient attention given to sustainability in their degrees, as they mention having no or low expectations that their programs would cover sustainability issues when they initiated their studies.

Given the interesting findings of this research, there are several directions that future investigations could take. Firstly, expanding the research scope to include a larger number of students and degrees, both from the same countries, to draw more accurate country-specific conclusions, and from other countries to further understand how students' perspectives change across the different European regions. The dissemination of a survey among a larger pool of European IEM Students could be beneficial for this purpose, as it would help validate the findings and reduce potential biases from researchers' interpretations, or students not fully understanding the sentences which they were asked to rate or the discussions. Considering the wide range of students' perspectives on the coverage of relevant competencies for working on sustainability-related projects within IEM programs, another topic of interest would be to explore which skills students consider relevant to work in such a project and how these can be integrated into IEM degree programs. Finally, continuing the ongoing investigation on how sustainability can be addressed in IEM programs without compromising the program's core content is of the utmost importance to tackle the dissatisfaction expressed by the students.

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Staff Experiences of Leading Large-Scale Multi-Departmental Project-Based Learning for Year 1 Engineering Students

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ABSTRACT

There is increasing consensus that Engineering programmes need to include space for skills learning, particularly in interdisciplinary contexts. Active learning methods, such as project-based learning, are the gold standard for teaching interdisciplinary skills. However much of the literature on these approaches focuses on relatively small class sizes, making the application in larger contexts seem unfeasible. The Integrated Engineering Programme (IEP) at University College London (UCL), is one of the most comprehensive and largest applications of active learning methodologies within undergraduate engineering curricula in the UK. A key part is the cornerstone module, Engineering Challenges. This first-year undergraduate module aims to introduce students to project work and key skills such as teamwork and

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communication through undertaking an interdisciplinary project. Taken by close to 1000 students across seven departments, this is a complex undertaking and we have had to develop approaches to delivering large-scale interdisciplinary project work. Team teaching is central to this; with the Engineering Challenges teaching team led by a faculty-level Module Lead, with one to four academics from each department. This paper focuses on the role of the Module Lead in this unusual situation, how this role differs from a more typical role and how this links to module success.

1 INTRODUCTION

There is an increasing focus within the Engineering Education community on preparing students for careers after university with the inclusion of space within the curriculum for skills learning. The World Economic Forum's Future of Jobs Report consistently discusses the need for new graduates to have a mix of professional skills, global competency, and technical knowledge (World Economic Forum, 2020). Given the complexity of future workplaces and the problems our graduates will be asked to tackle, learning these skills in an interdisciplinary context is increasingly necessary. Active learning methods, such as project-based learning (PjBL), are the gold standard for teaching skills in a wide range of contexts (Kolb, 2015). Leaders within Engineering Education have incorporated these methods in their curricula for several years now and wide spread adoption is rapidly becoming the norm (Graham, 2018).

1.1 UCL's Approach to Incorporating Skills-Based Learning

The Integrated Engineering Programme (IEP) at University College London (UCL), is one of the most comprehensive and largest applications of active learning methodologies within undergraduate engineering curricula in the UK (Mitchell *et al*, 2019). Active learning approaches are central to the IEP student experience where they are threaded throughout the common, cross-faculty teaching framework. A key part is the cornerstone Engineering Challenges module. This first-year undergraduate module aims to introduce students to project work and key skills such as teamwork and communication through undertaking an interdisciplinary project. Taken by close to 1000 students each year across seven departments, with material tailored to students' disciplines, this is a complex undertaking (Truscott *et al*, 2021).

In this way Engineering Challenges provides a significant contrast to what we might consider a typical module. In this paper a typical module is one where there is one or two academics who plan and deliver all of the teaching and assessment and it takes place within one department. In terms of scale a typical module would have a number of students where there are lots of available rooms and provide a reasonable teaching load for the one or two academics running the module. At UCL we estimate this to be between 50 and 100. In this typical module, the person leading it has control of all the pedagogical aspects of the module and while administrative support is provided by a member of the department's teaching and learning administration team.

1.2 Difficulties in Large-Scale Active Learning

Much of the literature on active learning is focused on small class sizes (Graham, 2018, Guo, 2020, Hernández-de-Menéndez, 2019). Engineering programmes are commonly very popular and tend to have increasingly large class sizes as is the case at UCL. Simply scaling up small class methodology is not possible due to the unrealistic volume of resources, staff, time and space required. So modified active learning approaches that are practical for large classes are required. Team-teaching has not been widely used in HE contexts, but it is something that the IEP uses regularly (Mitchell *et al*, 2019). Team-teaching is used extensively in order to deliver large-scale interdisciplinary teaching. For this module, the teaching team is lead by the Module Lead based at faculty level and contains one to four (based on student cohort size) leads from each department that takes the module. It is very clear anecdotally that the Module Lead position within Engineering Challenges is very different to a typical Module Lead role. While we have previously gathered staff experiences of PBL and related approaches within departments, we haven't yet focused on the faculty level Module Leadership role (Mitchell and Rogers, 2020).

This study sets out to start identifying how the Engineering Challenges Module Lead role differs from a typical one and how this is linked to successful implementation and delivery of large scale interdisciplinary active learning, through project-based learning.

2 METHODOLOGY

The data discussed in this paper comes from a slightly larger research project on the views of those teaching within Engineering Challenges at all level. In that project staff who have held the Module Lead role in the past and currently were interviewed, and the current and most recent Departmental Leads were invited to join focus groups. In this paper we have focused on the data collected during the Module Lead interviews.

Interviews were chosen due to the very same sample size (only three people have ever held the Module Lead position for Engineering Challenges) and because it allowed for exploration of the topics discussed (Bell, 2005). This last reason was particularly useful given the unusual nature of both Engineering Challenges and the IEP and the lack of general consensus within the literature on large scale project work modules and team teaching within this context.

2.1 Data collection

Three staff members were interviewed for this small study: two past Module Leads and the person holding the role currently. As two of the authors are part of this group (ML1 and ML3), interviews were conducted by one of the other two authors who isn't involved in the delivery of the module. The interviews were semi-structured with topics decided beforehand by all four authors, but questions chosen by the interviewer. Interviews were conducted online via Microsoft Teams, recorded and auto-transcribed. The first Module Lead, referred to as ML1 in this paper designed, delivered and established the module from the start of the IEP in 2014, for two academic years until 2016. The second Module Lead, ML2, took over the leadership and continued in the role for two academic sessions until 2018. At which time the lead role changed hands again to ML3, who has led the module for last 5 academic sessions including through the recent pandemic years and is still Module Lead.

2.2 Topics Selected for Discussion

Interviewees were asked to discuss what the Module Lead role involved, their approach to it, the impact of scale, their thoughts on active learning approaches, the advantages and disadvantages of interdisciplinary teaching and if they could identify and comment on success factors and barriers in delivering the module.

2.3 Data Analysis

Thematic analysis was chosen as the data analysis method as we wanted to draw out the module leads' understanding of what their role involved and find commonalities across all three interviewees' experiences (Clarke *et al*, 2015). Engineering Challenges and the IEP itself are both relatively unusual within Engineering Education and so thematic analysis allows us to explore something with relatively little literature consensus. Two of the authors initially coded all three interviews, with one interview being coded by both for comparison. This was followed by discussion and consolidation of the final themes list amongst all four authors, as well as comparison to the themes that came from the focus group data (not part of this paper).

3 RESULTS

It is clear throughout the interview data, that the role of Module Lead within Engineering Challenges is very different to a typical Module Lead role. It has much more of an executive function, co-ordinating groups of staff (both academic and supporting) and providing vision, direction and resources, with relatively little involvement in what happens day to day in the classroom. This makes the role more similar to a programme lead or given the cross-departmental nature of the module, a faculty head of education. Although a small sample size given the very specific nature of those interviewed, there are several strong themes that emerge from the interviews conducted with the past and present Module Leads. Leadership was by far the most discussed theme in all three interviews, with interdisciplinary and interdepartmental working, student experience, scale, and teaching team all also featuring within all three interviews.

3.1 Leadership

For all three interviewees, as the job title of Module Lead suggests, leadership was key to their conception of what their role within the module was. This covered a wider range of aspects of leadership, which included the day-to-day project management of the module as well as providing vision and a path forward in times of large-scale change. From the interviews there were four key aspects to leadership within the Module Lead role Pedagogical, Organisational, Advocational and Facilitative.

The pedagogical leadership aspect covers both educational standardisation across the module, as noted by ML1,*"Module Lead has to make sure there's consistency of* *assessment so that they (- all the students) get a fair chance at being marked consistently with the same assessments, the same rubrics. You know, in the same way, in the same format, because if there are a number of markers, definitely a number of academics in the classroom explaining the assessment, there has to be one point of truth and that's where the Module Lead certainly has to come out in terms of organizing"*, as well as providing the way forward in times of large scale change such as the move to online teaching in 2020 as a result of the COVID pandemic, as outlined by ML3, *"That was a lot of what I was bringing. OK? How? What? What's the structure gonna look like when we make a big change, you know? Because it was like, OK, you're the Module Leader. We don't know what we wanna do - you know, come up with a kind of way forward for us to do that."*. While the need for pedagogical vision could be argued to be necessary in a typical Module Lead role, the need for someone to be thinking about consistency across the module is unique to large scale and/or interdisciplinary teaching where there are groups of people involved in the delivery of the module.

Organisational leadership within the module is likened to project management by ML2, *"So it's very much like a project managers."*. There is a key troubleshooting element during the running of the module as highlighted by ML3, *"I am the problem solver."*, as well as the structural work done prior discussed by ML1, *"There is definitely a pace through each of the projects that the departments have to follow and that is set by the Module Lead…So there are milestones that the department, the Module Lead sets."*. Again, here we can see the impact of large scale and/or interdisciplinary teaching on the Module Lead role, with the need for much more structure within the module as well as a much closer relationship with administration at all levels within UCL. (*"I guess you have to put it in place in order to manage the large scale and that's where the Module Lead comes in… operationalizing it; there has to be one decision maker at the end of the day, … there has to be one point of truth and that's where the Module Lead certainly has to come out in terms of organizing"* [ML1])

The active learning approach of Engineering Challenges may also require more involvement with the administrative side of the module due to the different administrative requirements. The need to advocate for the module, the teaching approach it uses and the resources and requirements it needs, is a key part of the Module Lead role due to the relative unusualness of the scale and approach as discussed by ML3, *"do a lot of representing the module to do with timetabling and central UCL for example, and the faculty."*. Here advocacy requires the Module Lead to be the voice of the module, arguing for resources and campaigning for particular approaches with entities across both the faculty and UCL as a whole.

Central to the educational success of the Engineering Challenges module is the facilitative leadership aspect of the Module Lead's role, as this enables the other three aspects. The ability to build and develop relationships with a wide range of people across the engineering departments and the wider UCL community is essential. ML2 comments on this central importance, *"It's having the skills to make the relationships and sort of bring people with you without trying to force issues."*, and is supported by ML3, *"the central organization, the central kind of mediator about it, the central kind of ability to bring everyone together and speak with one voice"*. Again, this is very different to a typical Module Lead role and is a function of both the large scale the module works on and the interdisciplinary nature of it. (*"So, you know it is team teaching and that is a very different way to even teaching a module with a partner or an academic lead and a supporting academic. The team teaching means that you need someone with Module Leadership to be there."* [ML1])

3.2 Interdisciplinary, Team Teaching and Scale

Following on from leadership four other significant themes arose in all three interviews, student experience, interdisciplinary and interdepartmental working, scale and teaching team. Student experience should be a key aspect of any Module Lead's role, however the other three themes are more topic or approach dependant. All three have already been briefly mentioned in the discussion of leadership but it is useful to consider them outside of their relationship of leadership of the module.

Interdisciplinary teaching within Engineering Challenges comes in two forms, 1) between Engineering disciplines and 2) through bringing in topics and disciplinary studies perceived to be outside of Engineering such as ethics. This can lead to clashes between disciplinary approaches that need to be resolved. This is highlighted by a comment by ML1, *"there is still that dynamic of computer scientists do this part, and the electrical students do this part or, you know, the civil engineers and the mechanical engineers do two different things. And I think that's the nature of disciplinary focused people coming into an interdisciplinary space and forcing the relationship that way"*. Moreover, as indicted by ML2, interdisciplinary teaching combined with scale can result in not having enough space to fully explore a topic, *"So if you're trying to so fuse it with some kind of social context or considerations, that's actually really difficult, with the scale of the students involved."*.

An interdisciplinary approach also means working across departments at an operational level. At UCL, a lot of its central educational administrative systems and services function around a department model, allowing for departments to each having their own approach to, for example, communication or student support. In order for a faculty level module such as Engineering Challenges to function the Module Lead needs to try and find consensus across departments as well as tap into central systems that assume teaching is happening at a departmental level. This has become even more important in the context of the pandemic emergency teaching when changes were prevalent and occurred at pace. ML3 reflects on how this aspect has become a major part of the Module Lead role as a result, *"bringing these departments together - so there are seven different approaches to teaching - there are seven different approaches to student support - there are seven different approaches to assessment, seven different approaches to communication with, like everything is slightly different every single time."* Additionally ML3 adds *"UCL central systems, when they come to me as Module Lead, assumes certain things about what I do."*.

Engineering Challenges is one of the biggest modules, if not the biggest module, at UCL and one of the biggest PjBL modules in Engineering globally. That scale in and of itself can be a barrier to what can be done within the module ML2 described the implications of scale as the person leading the module, *"The scale of it sometimes means, I think that you can do a bit less than you would like. That's the downside of it."*. ML3 also mentions it indicating that even normal straightforward parts of the module become complex and time consuming, *“as the number of students goes up, the logistics and everything isn't linear.”.*

4 CONCLUSIONS AND RECOMMENDATIONS

The need for an unconventional Module Lead role in a central position is key in the success of large scale interdisciplinary active learning modules such as Engineering Challenges. In this particular situation it is difficult to separate what parts of the Module Lead’s role relate to large scale, interdisciplinarity or an active learning approach. However it is clear that when implementing new educational activities within any of these three aspects, Module Leads will need to employ a different set of approaches and skills to those that are typically used in the role. Different structures will also be needed particularly when creating new interdisciplinary or large scale educational activities as centralised leadership seems to be central to the success of these. Institutional leadership will need to understand the non-typical nature of the Module Lead role and will need to think outside the box when putting in place large scale and/or interdisciplinary structures as well as the support needed for those leading this type of module or educational change. All three interviewees identified institutional buy-in and backing to be a key success factor, for example from ML2, *“We had to stamp of approval”*. Also, as we approach ten years of Engineering Challenges and the IEP, it’s clear that, in contrast to the stereotype of traditional lecturing, this approach to teaching isn’t static and provides opportunities for constant innovation and improvement, as highlighted by ML1, *“the module itself is really evolved”* and ML3, *“it's always a work in progress, it's always evolving”*. This is can be very useful way to improve student experience and reflect on current events or thinking but does incur a resource penalty which needs to factored into things like teaching load.

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ENGINEERING SCIENCE STUDENTS' SELF-REGULATION: A BASELINE

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ABSTRACT

Today's society is characterized by swift technological advancements. Engineers cannot solely rely on what they learned at university, as new technologies pop up quickly. They need to participate in lifelong learning (LLL) in order to keep up with the state-of-the-art. Self-regulation is a core competency for lifelong learning that can be used as a proxy for it in an educational context. This study aims to establish a baseline for engineering students' self-regulation. Their levels are measured by the Self-Reflection and Insight Scale (SRIS), consisting of three subscales: need for self-reflection, engagement in self-reflection, and insight. 1128 students enrolled at KU Leuven's Faculty of Engineering Science (response rate = 36.6%) completed the SRIS. Mean scores are compared across study phases by use of Kruskal-Wallis and post-hoc Wilcoxon tests. Effect sizes are interpreted using Cohen's d. Students' engagement in reflection does not differ significantly across cohorts, but some significant differences are found in terms of need for reflection, insight, and self-regulation as a whole. The engineers' results are compared to other SRIS measurements reported on in the literature. Our study shows

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differing scores between males and females, which contrasts other studies' findings. Over the next three years, the SRIS will be administered to the same cohorts to determine whether a natural growth exists. These results will be supplemented with qualitative methods to gauge the effectiveness of future interventions.

1 INTRODUCTION

Engineers learn to work with contemporary technologies as part of their studies. As technological advancements succeed one another at a very rapid rate in today's society, it is important that engineers continue to keep track of new findings in their field and participate in lifelong learning [1]. Lifelong learning competencies, which prepare students for successful learning after higher education, are thus of great importance. Higher education institutions can have a big impact on their development in future engineers.

Developing lifelong learning competencies in engineering students is not straightforward though, as there is no consensus yet as to what exactly the umbrella competency of lifelong learning entails [2, 3]. Earlier research finds several competencies to be essential for lifelong learning, including metacognition and self-regulation [4]. Self-regulation has even been established as a core competency that can be used as a proxy for lifelong learning in the context of education [5], an approach also taken in this research.

In this paper, a first measurement of Flemish Engineering Science students' self-regulation levels is presented. We refer to the results as a baseline for students' self-regulation, as a proxy for lifelong learning. This baseline is a first essential step in our longitudinal research on the natural growth of self-regulation in engineering students, and by extension their lifelong learning competencies. Additionally, this baseline will also aid in evaluating the effectiveness of our future interventions on self-regulation. Belgium's higher education system offers several types of engineering programs. The most common ones are Engineering Science, Engineering Technology and Bioscience Engineering. Our overarching longitudinal research is concerned with all three of them. While this paper presents results related to Engineering Science students, a similar baseline for Engineering Technology students by the authors is currently in proceedings [6].

This paper addresses the following research questions:

- RQ1: What are Flemish Engineering Science students' baseline self-regulation levels?
- RQ2: To what extent do these levels differ across different study phases?
- RQ3: To what extent do these levels differ between male and female students?

Section 2 outlines this research's methodology, including the context in which the survey was administered, an overview of which students were given the opportunity to participate, and a note on how data was collected, processed and analyzed. The results, presented in Section 3 in tabular and graphical form, are further discussed in Section 4, where the findings are compared with those presented in the literature. To conclude, Section 5 provides a brief summary of the obtained results.

2 METHODOLOGY

2.1 Context and Participants

Flemish Engineering Science students' higher education starts with a three-year bachelor program, after which students follow a two-year master program. In this paper, students' progress in these programs is referred to as their study phase: either they are currently enrolled as a bachelor student (BA1, BA2 or BA3), or they are in one of their master years (MA).

2.2 Survey and Collected Data

Grant et al. define self-reflection as "(...) the inspection and evaluation of one's thoughts, feelings and behavior" and insight as "(...) the clarity of understanding of one's thoughts, feelings and behavior" [7]. They developed the Self-Reflection and Insight Scale (SRIS) and argue that it can be used to measure self-regulation. The SRIS is a 20-item scale that consists of three subscales: need for self-reflection (n = 6, e.g. *"I am very interested in examining what I think about"*), engagement in self-reflection (n = 6, e.g. *"I frequently examine my feelings"*), and insight (n = 8, e.g. *"My behavior often puzzles me"*). Participants are asked to rate the 20 items on a 1-5 Likert scale: a score of 1 corresponding to 'Strongly disagree', and a score of 5 denoting 'Strongly agree'. Statements can be positively or negatively phrased. Roberts and Stark confirmed that the three subscales behave as factors [8]. A Dutch translation of this survey, validated by Van den Broeck and Langie, was offered to bachelor students of the three phases and to second-year master students enrolled at KU Leuven's Faculty of Engineering Science. The survey was not offered to first-year master students because this group is less suitable for comparison with students of one-year master programs. The survey was presented as part of an on-campus lecture and students who were not present could access it through a link on the online learning platform used by KU Leuven. Participation was voluntary. To supplement the students' SRIS results with their current study program, phase, and sex (as listed on their ID), their university ID and e-mail addresses were also collected to allow for matching with university background data. This study is approved by the Social and Societal Ethics Committee (SMEC) (G-2022-5676).

2.3 Data Processing and Analysis

1128 responses were collected, corresponding to a response rate of 36.6%. Only fully completed entries were withheld (n = 1045), resulting in a response rate of 33.9%.

Negative statement scores were inverted and a score for each factor was calculated by taking the average score over all items loaded on that factor. An average over all statements was calculated to represent an overall self-regulation score.

Data was analyzed using nonparametric Kruskal-Wallis tests, followed by post-hoc paired Wilcoxon tests if the Kruskal-Wallis proved to be significant. Cohen's d was calculated to gauge the effect size of the identified significant differences. Scale reliability was measured using Cronbach's alpha and considered to be good ($\alpha = .80$).

3 RESULTS

3.1 RQ1: What are Flemish Engineering Science students' baseline self-regulation levels?

Table 1 presents the descriptive statistics for Engineering Science students' overall SRIS scores (self-regulation), and the scores on the three subscales (Engagement in Self-Reflection, Need for Self-Reflection, and Insight). The scores are reported separately per study phase.

3.2 RQ2: To what extent do these levels differ across different study phases?

Figure 1 visualizes the results reported in Table 1. Engineering Science's self-regulation as a whole does not differ across groups, nor does students' engagement in reflection.

First-year students report a higher need for self-reflection than second-years ($d = 0.36$, $p < .000$) and third-years do ($d = 0.39$, $p < .000$). Third-year students rate themselves slightly higher on insight than second-year students do ($d = 0.23$, $p = .009$).

Table 1: Engineering Science students' overall self-regulation levels, and levels of engagement in self-reflection (Engagement in SR), need for self-reflection (Need for SR), and insight on a 1-5 scale per study phase.

Study Phase	**Self-Regulation**		**Engagement in SR**		**Need for SR**		**Insight**		
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*n*
1st (Bachelor)	3.50	0.42	3.50	0.69	3.65	0.65	3.38	0.56	231
2nd (Bachelor)	3.42	0.47	3.37	0.72	3.39	0.75	3.47	0.64	496
3rd (Bachelor)	3.35	0.52	3.39	0.77	3.34	0.90	3.33	0.66	256
Master	3.38	0.49	3.37	0.73	3.46	0.83	3.34	0.66	62
All	3.42	0.47	3.40	0.73	3.44	0.78	3.41	0.63	1045

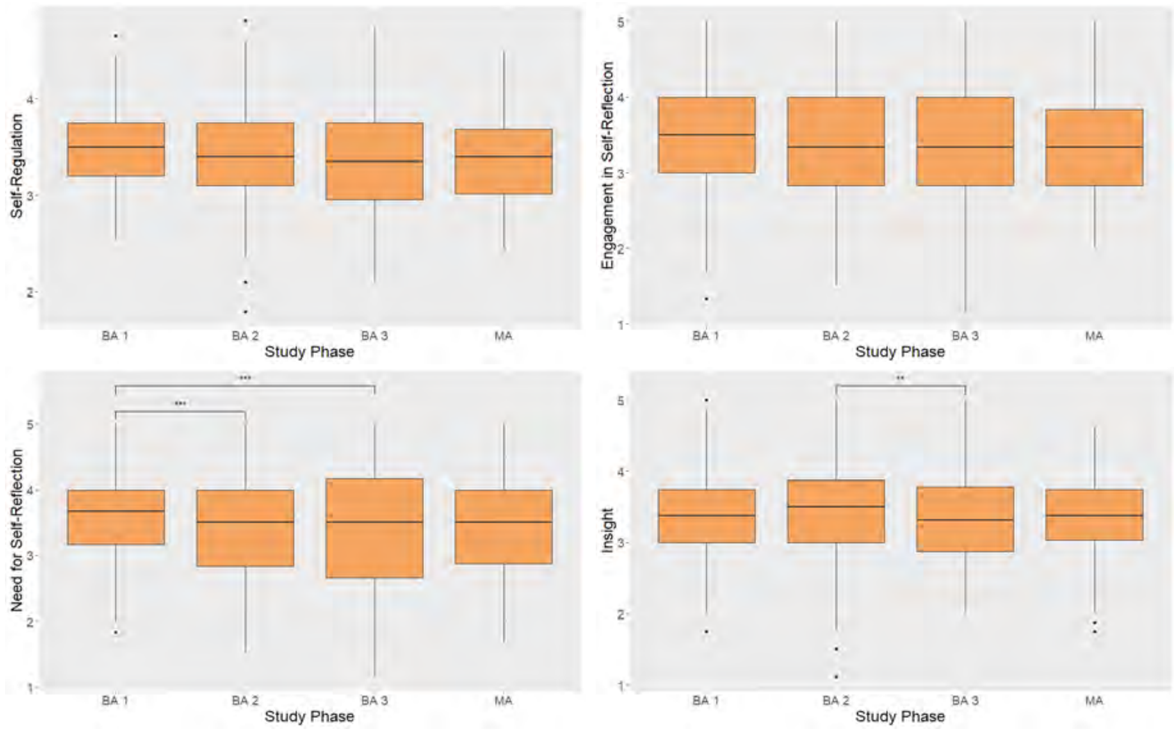

Figure 1: Distribution of scores per study phase. Left to right, top to bottom: Self-Regulation, Engagement in Self-Reflection, Need for Self-Reflection, Insight.

3.3 RQ3: To what extent do these levels differ between male and female students?

Table 2 provides a summary of SRIS scores grouped by sex. Figure 2 offers a visualization of these results.

Students' self-regulation as a whole does not differ significantly between males and females for any study phase. Males report less engagement in self-reflection than females in their first (d = 0.42, p = .017) and third years (d = 0.33, p = .017). Similarly, first-year (d = 0.42, p = .017) and third-year males (d = 0.36, p = .011) also rate their need for self-reflection lower than their female peers. When it comes to insight, however, males report higher levels than females in all study phases (d_{BA1} = 0.51, p_{BA1} = .006; d_{BA2} = 0.32, p_{BA2} = .018; d_{BA3} = 0.33, p_{BA3} = .028; d_{MA} = 0.72, p_{MA} = .036).

Table 2: Male and female engineering students' average self-regulation levels, along with their scores on the three subscales: Engagement in Self-Reflection (Engagement in SR), Need for Self-Reflection (Need for SR), and Insight.

Study Phase	**Self-Regulation**		**Engagement in SR**		**Need for SR**		**Insight**		
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*n*
Males									
1st (Bachelor)	3.49	0.41	3.45	0.68	3.60	0.64	3.43	0.55	191
2nd (Bachelor)	3.41	0.47	3.36	0.71	3.37	0.76	3.49	0.64	446
3rd (Bachelor)	3.33	0.51	3.32	0.74	3.27	0.91	3.38	0.67	194
Master	3.38	0.48	3.30	0.74	3.36	0.89	3.46	0.58	46
All	3.41	0.47	3.37	0.71	3.40	0.79	3.45	0.63	877
Females									
1st (Bachelor)	3.54	0.48	3.73	0.70	3.87	0.67	3.15	0.58	40
2nd (Bachelor)	3.44	0.49	3.53	0.77	3.59	0.64	3.29	0.55	50
3rd (Bachelor)	3.41	0.56	3.60	0.84	3.56	0.85	3.16	0.58	62
Master	3.39	0.53	3.56	0.71	3.74	0.57	3.00	0.79	16
All	3.45	0.52	3.60	0.77	3.66	0.73	3.18	0.60	168

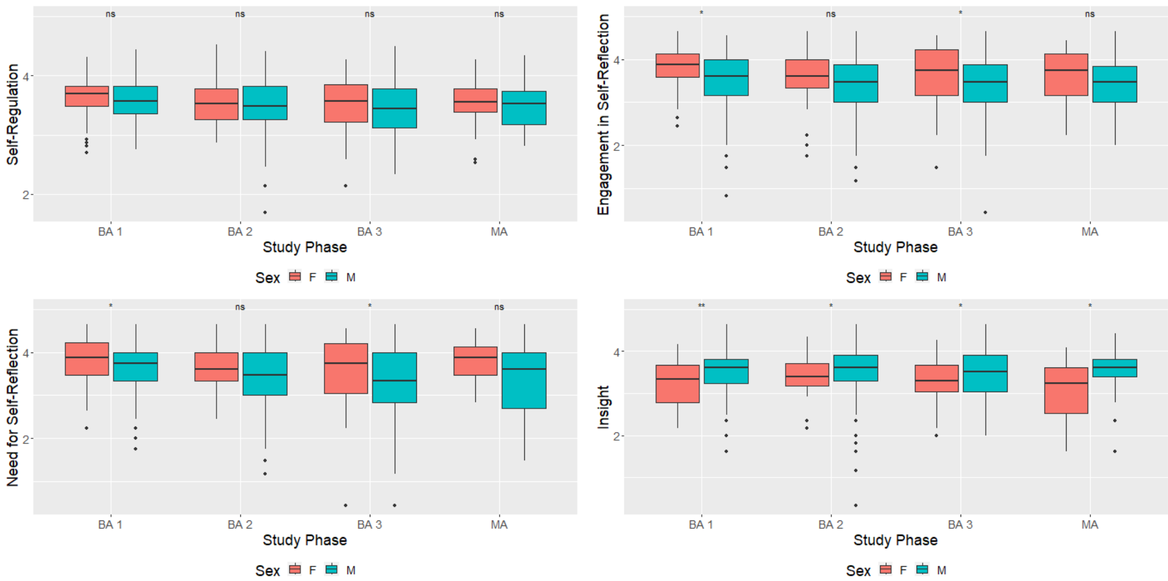

Figure 2: Distribution of scores per study phase and sex. Left to right, top to bottom: Self-Regulation, Engagement in Self-Reflection, Need for Self-Reflection, Insight.

4 DISCUSSION

To allow for a meaningful comparison and interpretation of the obtained results, it is necessary to know how students at other universities and from other disciplines rate themselves on the SRIS. To this end, a literature search was conducted to look for studies that administered the SRIS to university-level students of different countries and disciplines. Table 3 summarizes these results as reported on in the literature. If the SRIS was administered using a different Likert scale or factor calculation (e.g. taking the sum instead of averaging), the reported descriptive statistics were recalculated to make them comparable to KU Leuven's results. Grant et al. originally intended for the survey to load on three factors, but could only confirm two [7]: self-reflection and insight. Hence, they only reported a score for a combination of engagement in and need for self-reflection, instead of separate values. Some authors follow their example. These are marked with an asterisk in Table 3, in which we duplicated their self-reflection result for both engagement in and need for reflection. Roberts and Stark, on the other hand, verified that the three-factor structure is valid for medicine students, which is the approach taken by this study. Some authors report scores for more than one group. For example, Grant et al. present separate scores for people who keep a diary and those who do not. If an aggregate of all groups is available, this score is included as such in Table 3, otherwise the pooled mean and standard deviation are calculated by the authors. Mosalanejad et al. present SRIS measurements taken before and after an intervention. As there is no intervention in our study, their pre-test measurements are more appropriate for comparison and have hence been included in Table 3. Results from a previous study by the authors, measuring the self-regulation levels of students of a different Flemish engineering program called Engineering Technology, have also been included [6].

Table 3: Engineering Science students' average SRIS scores, repeated from Table 1, compared to those found in the literature. Studies that only report a score for self-reflection as a whole are marked with an asterisk (*).

Study	**Domain**	**Country**	**Engagement**		**Need**		**Insight**	
			M	*SD*	*M*	*SD*	*M*	*SD*
KU Leuven	Engineering	Belgium	3.40	0.73	3.44	0.78	3.41	0.63
KU Leuven [6]	Engineering	Belgium	3.33	0.72	3.41	0.72	3.35	0.63
Grant [7] *	Psychology	Australia	3.40	0.41	3.40	0.41	2.77	0.41
Nakajima [11]	Psychology	Japan	3.32	1.01	3.28	1.07	2.90	1.05
Roberts [8]	Medicine	UK	3.90	0.65	3.75	0.67	3.64	0.62
Naeimi [12]	Medicine	Iran	3.88	0.80	3.96	0.81	3.62	0.94
Carr [13]	Medicine	Australia	2.81	0.36	3.54	0.63	2.41	0.37
Paloniemi [14]	Medicine	Finland	3.27	0.75	3.75	0.72	3.01	0.50
Mosalanejad [10]	Medicine	Iran	2.96	0.45	2.77	0.43	2.55	0.33
Bulmer [15] *	Healthcare	USA, Canada	3.86	0.72	3.86	0.72	3.64	0.70
Aşkun [16]	Mixed	Turkey	3.26	1.23	3.50	1.18	3.10	1.17
Harrington [17] *	Mixed	USA	3.38	0.76	3.38	0.76	3.66	0.70

Engineering Science students and Engineering Technology students report similar levels on all subscales [6]. Even though the differences on the engagement and insight subscales are significant, their effects are very small ($d_{ENG} = 0.10$, $p_{ENG} = .026$; $d_{INS} = 0.09$, $p_{INS} = .018$). In the rest of the discussion, Engineering Science students are simply referred to as engineering students and only their results, as reported in Section 3, are used for comparison.

Along the spectrum of scores found in the literature, our engineering students appear to score rather average on all three subscales. When it comes to engagement in self-reflection, the medicine and health care students of Roberts and Stark, Naeimi et al. and Bulmer et al. rate themselves at least 13.5% higher than our engineers. That is not to say that medicine students engage more in self-reflection than engineering students do, as the lowest scores also concern medicine students. Grant et al., Harrington and Loffredo and Nakajima et al. report (engagement in) self-reflection scores very similar to our engineering students, their samples being taken from either a mixed pool or psychology students. Our engineering students appear to rate their need for self-reflection somewhere in the middle as well. There is no clear pattern as to which disciplines or countries experience more or less of a need than others. In future studies, a combination of quantitative SRIS ratings with qualitative insights may help interpret these divergent results. With a mean score of 3.44, our engineering students have reported a level similar to that of Aşkun and Cetin's, Harrington and Loffredo's, Carr and Johnson's and

Grant et al.'s students. The insight levels reported by the our engineering students appear to be relatively high. Roberts and Stark, Bulmer et al., Harrington and Loffredo, and Naeimi et al. all report higher mean insight scores ranging from 6.2% to 7.3% higher than our engineers' average. Aşkun and Cetin's Turkish students report the highest insight ratings among the other studies, leaving a 9.1% gap between them and our engineering students.

We found that male engineering students report lower levels of engagement in and need for self-reflection, and higher levels of insight than females do. These findings are in contrast with some results of other studies, such as those by Chang et al. [18], Carr and Johnson, Paloniemi et al. and Grant et al.. Roberts and Stark also observe that males report higher levels of insight, but find no differences when it comes to the other factors. Aşkun and Cetin claim the opposite: in their study, males score higher on the combined self-reflection subscale, but there is no significant difference when it comes to insight. Our male and female students do not exhibit significant differences when it comes to their total SRIS score, but this total score is the result of differently distributed subscale scores. As presented in Section 3, females report lower levels of insight than males do. First-year and third-year females report a higher need for, and more engagement in, self-reflection than their male peers do. Evidently, these differing scores on the subscales even out when summed up to the total SRIS score. It is unclear whether the total SRIS score can be validly compared across these cohorts, as it is not indicative of the same subscale levels. Consequently, we advise that researchers always look at the distribution of the subscale scores and not only look at the total SRIS result. Alternatively, triangulation by supplementing with qualitative measurements may also help interpret results.

The differences between engineers in different stages of the study program are in contrast with studies by Bulmer et al. and Roberts and Stark, who report no significant differences between such groups. Carr and Johnson report an increase in need for self-reflection, as well as a decrease in engagement in self-reflection, towards the end of the program. These findings also contrast with the results presented in this paper, as engineering students report a lower need for self-reflection towards the end of the program and their engagement in self-reflection does not differ significantly. Our engineering students also exhibit a small apparent increase in insight, whereas the medicine students of Carr and Johnson's study do not.

Self-report instruments such as the SRIS have their limitations [19] and it is unclear to what extent the obtained results are influenced by this. The complexity of the self-regulation construct further aggravates this problem, as what is measured by the survey may also partially be attributable to other, unknown factors. To help clarify these and future results, follow-up research utilizing qualitative methods will be conducted to help discover an explanation for the observed effects.

5 SUMMARY AND ACKNOWLEDGMENTS

This paper presents a baseline for Flemish engineering students' self-regulation levels. These students report scores that are neither particularly high nor low when compared to other SRIS measurements presented in the literature. Some differences between male and female engineers can be observed in terms of self-reflection, and males report higher levels of insight than female engineers do.

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Effects of Gaze Distribution on Woodworking Knowledge and Skills

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ABSTRACT

This study investigates the gaze distribution of learners who watched a video about making a screw joint (a woodworking process) and explores its relationship with knowledge comprehension and skill acquisition levels. Twenty university students who had never taken a specialized class on screw joints participated in the study. They watched approximately a three-minute video on making a screw joint and completed knowledge comprehension and skill acquisition surveys based on the video content. Gaze measurements were conducted using Tobii T120, a screen-based eye-tracking device manufactured by Tobii Technology. In the line-of-sight

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distribution analysis, the objects appearing in the video were categorized into four areas of interest (AOI): human faces, processed areas, subtitles, and tools. Further, the viewing rates for each AOI were calculated. The rates were ranked in descending order: processed areas, human faces, subtitles, and tools. Correlation analysis showed no significant correlation between knowledge comprehension and AOI. However, significant correlations were found between skill acquisition and human faces ($r = .477$, $p < .05$), subtitles ($r = -.531$, $p < .05$), and tools ($r = .510$, $p < .05$). Furthermore, multiple regression analysis showed that human faces ($\beta = 0.52$, $p < .01$) and tools ($\beta = 0.49$, $p < .05$) positively affected skill acquisition. These results suggest that focusing on human faces and tools may enhance skill acquisition.

1 INTRODUCTION

Gaze measurement is expected to be useful for estimating learners' degree of comprehension, attention, performance, etc., for viewing content and designing teaching materials to encourage understanding and concentration. Several studies have investigated the relationship between gaze and comprehension, attention, performance, etc. This includes research on gaze movement and reading comprehension (Cheng et al. 2015; Fahey et al. 2011; Vo et al. 2010) and the relationship between gaze and attention (Min and Corso 2021; Nishiyama et al. 2022; Oishi et al. 2021). A study was also reported on gaze and performance that utilized users' gaze to examine the role of a mirroring tool (i.e., Exercise View in Eclipse) in orchestrating basic behavioral regulation of participants engaged in a debugging task (Mangaroska et al. 2018).

In recent years, digital content such as digital textbooks and YouTube have been used to improve learning quality. When a learner views digital content, the gaze direction, which is where to observe carefully, is an important viewpoint and significantly affects the degree of comprehension. For example, a gaze-based system has been developed to assist users in note-taking while watching lecture videos (Sharma et al. 2014); a gaze-based indicator of students' attention in a Massive Open Online Course (MOOC) video lecture has been proposed (Nguyen and Liu 2016). Therefore, conducting research focusing on gaze distribution in manufacturing in Technology and Engineering Education is necessary. Clarifying what beginners studying manufacturing focus on when viewing digital content, the knowledge they attain, and the skills they can acquire can provide beneficial suggestions for learning content.

This study investigated the gaze distribution of learners who watched a video on screw joint making (a woodworking process) and explored its relationship with knowledge comprehension and skill acquisition levels. To the best of our knowledge, there are no studies clarifying the relationships between the gaze distribution and skill improvement of screw joint making by using eye-tracking technology. Therefore, the findings of this study will be useful for learning guidance when using video teaching materials.

2 METHODOLOGY

2.1 Participants

A total of 20 (11 males and 9 females) healthy university students aged 20 to 24 years (mean age 21.90 years) participated in this study. All participants did not have knowledge on screw joint making, which were selected by preliminary survey. Before the experiment started, the purpose and procedure of this study were explained and informed consent for participation was obtained from all participants.

2.2 Video teaching material

A video of a screw joint making of which the participants lack the knowledge was selected. The video is a teaching material in the digital textbook of a junior high school for Technology and Engineering Education in Japan (Tokyo Shoseki co., ltd. 2016), which was created for beginners and judged to be appropriate for the participants. The video lasted for 2 minutes and 53 seconds.

2.3 Knowledge comprehension survey

For measuring knowledge comprehension, the participants were asked to answer 12 questions about the video content they watched using survey forms. Questions 1 and 2 asked participants to answer the names of the hand gimlet auger (Japanese Kiri) types. In questions 3-10, the participants were asked to answer (fill in the blanks in the text) the screw joint procedure. Questions 11 and 12 were short-answer questions. Question 11 examined in what order participants would screw in and why they had multiple screws. Question 12 enquired participants how and why to choose a screwdriver correctly. The 12 questions totaled 100 points. Questions 3, 4, 8, and 9 scored 5 points each, whereas the remaining questions scored 10 points each.

2.4 Skill acquisition survey

To measure skill acquisition, participants were asked to complete skill acquisition surveys based on the video content. The complete sample comprises the following items on the workbench where the participants worked: 6 countersunk head wood screws (thickness 3.1 mm x length 25 mm), a square drill (total length 300 mm x needle diameter 3.5 mm), a triangular drill (total length 340 mm x needle diameter 3.5 mm), a counter sink drill (12 mm), a three-pointed Japanese drill bit, called nezumibagiri (3 mm), cross screwdriver (axis length 40 mm x axis width 6 mm), one scribed wooden board A (thickness 12 x width 150 x length 330), two scribed wooden boards B (thickness 12 x width 150 x length 65), scrap wood for underlay, and a jig for stably standing upright wooden boards B. Before initiating the work, the participants were instructed to follow the procedure shown in the video: select appropriate tools, consider safety, and use scrap materials and jigs for the underlay. The viewpoints of skill evaluation are as follows:

●Viewpoint of the items in progress

(1) A pilot hole was drilled using a triangular drill.

(2) The pilot hole depth was approximately two-thirds of the wood screw.

(3) A countersink drill was used for countersinking.

(4) The screwdriver was properly used.

(5) The screw heads on the screws were completely screwed in.

(6) The screws were tightened orderly (from outside to inside).

(7) No deviation from the scribed line before starting the screw joint was confirmed.

(8) No deviation from the scribed line was confirmed before the complete embedding of screw joints.

●Viewpoint of the finished product

(9) No part deviated by more than 2 mm from the scribed line.

(10) All the screws were screwed in until the end.

(11) No gap of 2 mm or more was present between the ground and two wooden boards B (no rattling).

Eleven viewpoints totaled 100 points. Viewpoints 7 and 8 were worth 5 points each, and the remaining questions were 10 points each.

2.5 Experimental procedure and gaze measurement

First, the participants watched the video teaching material. Fixing the face and body of a participant during the eye-gaze measurement was possible because the eye-gaze measurement was performed in a video. Therefore, a screen-based eye-tracking device called Tobii T120, manufactured by Tobii Technology, was used. As a precaution before viewing, participants were informed that they had to measure their gaze while watching the video. They could relax while watching but could not move their heads or bodies as much as possible. In addition, as a survey would be conducted after the video, they must understand the content. Subsequently, because the shape of the eyes differs, calibration (processing to measure differences due to eyeball size, presence or absence of contact lenses, and ambient lighting environment) was performed before the participants watched the video. Knowledge comprehension surveys were conducted after watching the video. Finally, skill acquisition surveys were conducted.

2.6 Gaze distribution analysis method

In the line-of-sight distribution analysis, the objects appearing in the video were categorized into four areas of interest (AOI): human faces, processed areas, subtitles, and tools. The viewing rates for each AOI were calculated. When the scene of the video teaching material changed, it was necessary to reconfigure the AOI in each scene. The video teaching material was divided into 31 scenes. The time spent watching human faces, processed areas, subtitles, tools, and other areas that appeared in the 31 scenes was totaled, and the participants measured where and how long they watched the approximately three-minute video. The analyzable data differed for each participant. Therefore, we calculated the gaze ratio to the locations where the AOI was set during gaze measurement.

3 RESULTS

3.1 Video viewing trends

The length of time the participants watched the four objects set in the AOI as they appeared in the video was calculated. Table 1 shows the average data of 20 participants.

Table 1. Percentage of the time the gaze was directed to the appearance time of the AOI setting (mean of 20 people)

	Human faces (%)	Processed areas (%)	Subtitles (%)	Tools (%)
Mean	17.66	57.50	16.81	8.08

The proportion of gaze directed is higher in the order of processed parts, human faces, subtitles, and tools. The percentage of processed parts was 57.50%, which were the scenes participants could easily pivot their eyes. The percentages of human faces and subtitles were 17.66% and 16.81%, respectively. The percentage of tools used was the lowest at 8.08%.

3.2 Relationship between gaze distribution and knowledge comprehension and skill acquisition

Table 2 shows the participants' knowledge comprehension and skill acquisition survey scores. Pearson's product-rate correlation coefficients were calculated using the percentage of participants who watched the AOI settings, their comprehension scores, skill scores, and the mean scores for both, as shown in Table 2. Table 3 provides the correlation coefficients. No significant correlation was found between the comprehension scores and the percentage of participants watching the AOI setting, suggesting a least significant relationship between eye gaze and comprehension. However, a positive correlation was found for human faces ($r=.477$, $p<.05$) and tools ($r=.510$, $p<.05$), and a negative correlation was found for subtitles ($r=-.531$, $p<.05$) to the skill scores. Multiple regression analysis was conducted using the skill scores and percentages of participants who watched human faces, subtitles, and tools to examine the causal relationship. The results of the multiple regression analysis are presented in Table 4.

Table 2. Participants' scores on the comprehension and skills surveys

Participants	Comprehension	Skill	Mean score
A	75	85	80
B	70	80	75
C	70	85	77.5
D	95	100	97.5
E	80	60	70
F	90	75	82.5

G	45	50	47.5
H	65	90	77.5
I	50	55	52.5
J	55	80	67.5
K	80	75	77.5
L	75	75	75
M	65	80	72.5
N	90	75	82.5
O	60	60	60
P	65	70	67.5
Q	80	80	80
R	90	75	82.5
S	75	80	77.5
T	75	85	80
Mean value	72.5	75.8	74.1

Table 3. Correlation coefficient between AOI settings, comprehension score, and skill score

	Human faces	Processed areas	Subtitles	Tools	Other
Comprehension	.214	-.005	-.009	.129	-.066
Skill	.477*	-.137	-.531*	.510*	.133
Mean score	.386	-.076	-.291	.353	.032

* p<.05

Table 4. The results of the multiple regression analysis

	Standard error	Standard partial regression coefficient	t-value
Human faces	1.518	.517	3.040**
Subtitles	.687	-.175	-.867
Tools	1.131	.487	2.418*

* p<.05, ** p<.01

The results showed a significant multiple correlation coefficient (R^2=0.587, p<.05). The tools (β=0.487, p<.05) positively affected skill acquisition. The degree of skill acquisition was considered to increase by focusing their eyes on the tools. Possibly, by watching the tools, the participants understood the usage and structure of the tools used in the video and could proceed with the work with an advantage. As shown in Table 1, the percentage of participants who watched these tools was low. Focusing on tools has been suggested as effective.

Moreover, human faces (β=0.517, $p<.01$) positively affected skill acquisition. Although the comprehension gained by watching a human face does not seem necessary, understanding where to watch during the task and when looking for deviations from the scribed line is important. Therefore, when more people check other human faces and gaze while watching videos, their skills are improved while performing similar tasks.

Although multiple regression analysis showed no significant standard partial regression coefficient, Table 3 reveals a negative correlation ($r=-.531$, $p<0.5$) between subtitles and skill acquisition. Because the work on the video continues to progress even when the subtitles are on, participants are expected to be more likely to gain comprehension from other parts of the video if they read and comprehend the subtitles as quickly as possible.

4 CONCLUSIONS

The study results suggest that focusing on human faces and tools may enhance skill acquisition on screw joint making. Instructors must clarify the points they want students to concentrate on when they show videos for skill improvement. To improve skill acquisition, instead of just having the students watch a video, teachers could ask them in advance to focus on the gaze of the person working or what kind of tools the person is using.

However, this study does not confirm whether transfer of learning is observed when watching video teaching materials related to other tools. In addition, variables (e.g., psychological, age, personality) that may influence the conclusions need to be examined in the future. Finally, experiments with additional research participants are needed to obtain statistically stable results.

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Who funds engineering education research? Content analysis of funding sources reported in three top-tier engineering education research journals

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ABSTRACT

Engineering education research (EER) is becoming a globally connected field of inquiry but there is a lack of sustained funding opportunities available. Currently, it is not quantitatively known which entities are most prolific for providing funding for EER globally. This study attempted to map which entities were most commonly cited as providing funding for EER. Three top-tier EER journals were chosen, articles published in the journals during 2021 were identified. Metadata about each publication was downloaded from Scopus. Funding information for each publication was qualitatively analysed, then synthesised to provide a quantitative understanding of EER funding sources. There was a notable discrepancy between Europe and the USA. Many USA articles secured funding primarily from the National Science Foundation, whereas European articles were more likely to report funding from a

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range of different sources, including EU programs, state and national governments. This suggests that EER is given a higher priority in the United States and that the majority of this funding is channelled through the NSF. This has implications that growth of EER outside of USA may be restricted by limited funding opportunities.

1 INTRODUCTION

1.1 Background

Despite claims that engineering education research (EER) is becoming a globally connected field of inquiry (Borrego & Bernhard, 2011), the lack of sustained funding opportunities available for those involved has been noted in several locations including Australia (Dart, Trad & Blackmore, 2021; Godfrey & Hadgraft, 2009), Canada (Seniuk Cicek, Paul, Sheridan, & Kuley, 2020), Ireland (Sorby et al., 2014; Wint et al. 2022), New Zealand (Kumar, Gamieldien, Case & Klassen, 2021), Portugal (Sorby et al., 2014, van Hattum-Janssen et al. 2015), South Africa (Kumar, Gamieldien, Case & Klassen, 2021), and the UK (Wint & Nyamapfene, 2022; Wint et al., 2022), as well as within three Nordic Countries (Edström et al., 2016). To this end, the scale and frequency of funding offered by the National Science Foundation (NSF) in the USA does not appear to be replicated in other contexts, where EER has been claimed to fall outside the direct remit of national research funding bodies (Burke et al., 2020; Wint & Nyamapfene, 2022). For example, Malmi et al. (2018) claims that it is difficult to receive support for EER within Europe as it is not a good fit with the criteria defined for EU Horizon 2020 funding.

Such findings are significant, with the lack of EER funding having implications for the EER landscape as a whole. Firstly, funding is both important in attracting new scholars to EER but also in retention of researchers (Xian & Madhavan, 2013). Indeed, Wankat et al. (2002) remind us that the continuing growth of scholarship of teaching and learning in engineering relies on faculty having the same access to funds and support as those engaged in disciplinary research. However, the disparity between funding for technical and education research continues to exist (Dart, Trad, & Blackmore, 2021; Wint & Nyamapfene, 2022). Secondly, the availability of financial support is likely to impact upon the amount of EER publications. Sorby et al. (2014) claim that EER in the USA primarily emerged as a result of consistent funding, with two-thirds of publications within the JEE between 1998 and 2002 acknowledging funding from the National Science Foundation (NSF) (Wankat, 2004). In comparison, it is claimed that the lack of proactive funding on the European level as a contributory factor to the stunted development of EER in Europe (Edström et al., 2016).

Given the apparent relationship between funding of EER and the growth of EER, it is of interest to understand more about sources of funding. Previous work in the area focused on the sources of support acknowledged by the authors of publications within JEE (Wankat, 2004; Wankat, Felder, Smith, & Oreovicz, 2002), and changes in how the NSF has spent money on EER over time (Borrego, & Olds, 2011; Cady, & Fortenberry, 2008). However, there has not been a recent, large scale mapping of the sources of EER funding. As such, in this work we adopt a qualitative content analysis approach to determine the primary funding sources for EER described in three top-tier EER journals.

1.2 Research Question

- What are the primary funding sources for EE research described in three top-tier EE research journals?

2 METHODOLOGY

This study utilised a qualitative content analysis approach. Funding information from relevant EE publications were qualitatively analysed, then synthesised and presented to provide a quantitative understanding of EE funding sources.

2.1 Getting Funding Details of EE Research Publications

We identified engineering education research journals indexed by Scopus that were reported as being top-tier (quartile 1), according to the Citescore 2021 report published by Scopus. This identified the European Journal of Engineering Education (EJEE), IEEE Transactions on Education (IEEEToE), and Journal of Engineering Education (JEE) as being Q1 for the 2021 year.

Using the Scopus web interface, all the articles published by each of the three EE journals during 2021 were identified. The year 2021 was selected as it was the most recent year where it was certain that all the publications for that year had been captured by Scopus (indexing in Scopus may lag behind publishers by several months).

Following this, the Scopus records for each of the publications were downloaded as a csv file (one for each journal), which typically report about 50 data fields for each publication. Each article was uniquely identified by the acronym of the journal and the number of the article in the list (e.g. EJEE-8). This included information about reported funding which was typically captured in the “Funding Details” data field for each publication, or alternatively in the supplementary data fields about during such a “Funding Text 1” and “Funding Text 2”. It was also common that funding details were repeated several times (redundantly) across the “Funding Details” and “Funding Text 1” data fields, as the “Funding Details” data field often included only the names of the funders (and grant IDs) while the “Funding Text 1” data field often reported more details.

It is also important to note that the “Funding Text 1” field often included other information that was not relevant to this study, such as acknowledgements or thanks to reviewers. This is likely due to processes regarding how funding and other information is reported by each journal and indexed by Scopus. An example of reported funding information for several publications is shown in Table 1 for clarity purposes.

Table 1. Example excerpts of funding information reported about publications indexed by Scopus, showing selected relevant data fields

Article Title	Text in the “Funding Details” Scopus Data Field	Text in the “Funding Text 1” Scopus Data Field	Text in the “Funding Text 2” Scopus Data Field
Increasing gender diversity in engineering using soft robotics	National Science Foundation, NSF: DRL-1513175	This material is based on work supported by the National Science Foundation under Grant Number DRL-1513175.	National Science Foundation, Grant/Award Number: DRL-1513175
Constructive alignment between holistic competency development and assessment in Hong Kong engineering education	Research Grants Council, University Grants Committee, RGC, UGC: 17200720	General Research Fund of the Hong Kong Research Grants Council, Grant/Award Number: 17200720; University Grants Committee Teaching and Learning Fund, Grant/Award Number: HKU9/T&L/16-19	The research in this article was funded through the General Research Fund of the Hong Kong Research Grants Council (Project Reference Number 17200720) and the University Grants Committee Teaching and Learning Fund.
Faculty wide curriculum reform: the integrated engineering programme	UCL Engineering, University College London	We would like to thank all the staff and students of the UCL Faculty of Engineering Science for their commitment and dedication to the Integrated Engineering Programme.	

2.2 Analysis of Funding Details

The information about funding reported for each publication in the corresponding Scopus record (see Table 1) was then qualitatively coded with NVivo, using an inductive approach. Several coding themes emerged, which corresponded to different types of funding sources, or types of funding information. The coding themes were University Name, University Department Name, and Agency/Foundation/Funding Scheme.

The name of each university, university department name, agency, foundation, or funding scheme was coded as a separate sub-nodes within the overarching themes, so that it was possible to code repeated mentions of an entity to that same node. Examples of agencies, foundations or funding schemes include the National Science Foundation, European Commission, and Spanish Ministry of Science and Innovation. When the name of an agency, foundation or funding scheme was reported in a language other than English, the name of the entity was coded using the original naming given (i.e. names were not translated to English).

The coding that had been completed for every article by the first author was then checked by the second author, who used a separate spreadsheet to record possible issues in the original coding. Following this, the first author then reviewed the notes made by the second author and made minor changes to the original coding. Subsequent areas of remaining unclarity were discussed amongst the authors until a consensus was reached. All entries were then recoded to ensure consistency amongst the sample.

It is necessary to clarify that university names or departments were only coded when these were specifically reported in the relevant funding data fields within Scopus. When a university name was explicitly stated within the funding data fields within Scopus (like in row 3 of Table 1 above), it was assumed that the university had specifically provided funds for the purpose of conducting the research (i.e. it was assumed that this did not just reflect the salaries of the authors who were paid to conduct the research as part of their work at the university, otherwise every single publication would list all the universities that all the authors worked at). However, it is possible that authors' normal salaries paid by universities may have been inadvertently reported as funding for some publications. This is a limitation of the study.

3 RESULTS

3.1 Ratio of articles that received funding

Table 2 shows that approximately half of EJEE (47.4%) and half of IEEEToE (50.0%) publications report funding. In contrast, a higher percentage of JEE articles report funding (73.0%). The most common types of funding for all journals were agencies or entities other than universities (Table 3). Numerous articles also reported receiving funding from universities but often it was unclear if this was funding dedicated to the project or indirectly (such as through staff salaries).

Table 2. Number of articles published by each journal, and how many reported funding sources

Journal	Number of Articles Published in 2021	Number of Articles Which Reported Funding
EJEE	59	28
IEEEToE	54	27
JEE	52	38

Table 3. Most common sources of funding explicitly reported by publications in each journal

Journal	Agency Entries (total count)	University Name Entries (total count)
EJEE	28	20
IEEEToE	58	8
JEE	43	16
Total	128	43

3.2 Sources of funding from each country

Table 4 shows the origin of funding sources, based on country or international organisation (only the European Union). There was a mix of funding from agencies and universities across many countries. Spain and the United States included the highest number of agencies (12 each). The United States and Spain had the highest number of universities which funded research, at 18 and 6, respectively.

Table 4. Number of unique universities and agencies which provided funding for EE research from each country

Country/Region	Number of Unique Universities Named	Number of Unique Agencies Named
Argentina	1	N/A
Australia	2	N/A
Brazil	1	4
Canada	1	N/A
Chile	N/A	1
China	2	7
Colombia	1	N/A
Croatia	0	N/A
Denmark	1	N/A
European Union	N/A	7
France	N/A	1
Germany	N/A	1
Hong Kong	N/A	2
Ireland	N/A	1
Japan	N/A	1
Malaysia	1	N/A
Netherlands	1	1
South Africa	1	1
Spain	6	12
Sweden	3	N/A
UK	4	2
USA	18	12
Total	43	53

3.3 Most common sources of funding

Table 5. Most common sources of funding reported (excluding universities)

Funding Country/Union	Agency or Program	Number of Articles Which Mentioned Agency or Program As Funding Source
USA	National Science Foundation	47
European Union	All others	5
European Union	European Regional Development Fund	5
European Union	Erasmus+	5
Spain	Spanish Ministerio de Ciencia e Innovación	3

Table 5 shows the agencies which were named the highest number of times amongst all the articles published in the three journals in 2021. As shown, the NSF in the United States provided funding for the highest number of articles by far, at 47. The next highest was the European Commission, which provided funding for 15 article, though various sub-programs (e.g.Erasmus+, European Regional Development Fund). Moreover, there were a large number of articles which were funded by more than one NSF grant. Table 6 shows that 11 articles were funded by 2 NSF grants, while 4 articles were funded by 3 NSF grants.

Table 6. Articles funded by more than one National Science Foundation Grant

Number of National Science Foundation Grants	**Count**	**Article IDs**
2 National Science Foundation Grants	11	EJEE-12, EJEE-13, IEEETOE-20, IEEETOE-40, IEEETOE-54, JEE-7, JEE-27, JEE-38, JEE-41, JEE-43, JEE-44
3 National Science Foundation Grants	4	IEEETOE-3, IEEETOE-14, JEE-24, JEE-36

3.4 Contribution of funding source agencies, based on geographic region

The funding sources in Europe were quite scattered and not uniform. There were 49 articles published that were funded by 28 European Agencies. But the funding sources in the USA were a lot more concentrated. There were 54 articles published that were funded by 12 USA Agencies, Foundations, and Research Schemes. Of these 54 articles, 42 were funded by the NSF.

Table 7. Most common sources of funding reported, aggregated by regions (selected – not all shown)

Region	**Number of Unique Agencies, from Region**	**Number of Published Articles Funded by Agencies from Region**
Europe (all)	27	49
USA	12	54
China	7	12
Brazil	5	6

4 DISCUSSION

4.1 Reflections on findings

From a European perspective it is notable from Table 5 that while 47 papers in our sample reported funding from the US federal funding agency, only 17 were supported by European Union level funding. This suggests that EER is given a higher priority in the United States and that the majority of this funding is channelled through the NSF.

Furthermore, it is important to note that our data only allows us to compare how many papers were funded and who were the funders but does not provide information on the actual values of financial support provided by each grant. The only study we have found that presents comparative figures for the financial support provided by NSF grants compared with national funding in the EU is a 2015 study on Portugal that observes that funding for a typical NSF- supported project in the period 2000 to 2010 was more than 25 times higher than that for projects funded by the FCT, the equivalent Portuguese government agency. This could be a fruitful area for collaborative data gathering within SEFI to identify the scale of national funding awards in EU countries.

Within the European context, Table 4 shows that Spain is the most cited as providing support via national or institutional funding (18 reported sources in our sample). This aligns with a previous study that showed that Spanish authors were prolific in the field of EER in the period 2018 - 2019 (authors 2021). The UK is the next with 6 reported sources which again aligns with data in a previous study (authors 2022).

From a historical perspective, we have not found prior data on EER funding for Europe, South America or China but there is a study on the US context from 20 years ago that suggests that at that time NSF funding was at a notably lower level there. Wankat et. al (2002) examined 72 of the articles published in JEE during 1999. At that time, only 35% of articles reported receiving financial support, and 19% reported funding from the NSF. Comparing the findings of Wankat et. al (2002) with the findings in this study demonstrates that during the previous 20 years, the percentage of JEE articles which report funding (from any source) increased from 35% to 73%, and the percentage of articles which specifically reported NSF funding increased from 19% to 50%.

4.2 Limitations

There are several limitations of this study which must be noted. First, the sample of funding information was drawn from limited years, focusing only on publications from 2021. The sample of publications also was limited to top-tier EER journals, and did not include all EER journals or other publication venues such as conference proceedings or book chapters (although funding information for conference papers is often not recorded in Scopus). Some authors may also publish in languages other than English (also being in journals outside the 3 selected), which would also mean that potential sources of funding were not included in the sample of evaluated articles. The data relies on self-reporting by the authors. In some cases, it was unclear whether authors were supported financially and it is possible that authors forgot to mention any support they received. For example, in some cases it is plausible that authors acknowledge their own institution as their employer, as opposed to them providing specific funding for the research. The amount of monetary support may also vary significantly between sources.

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WORKPLACE SPACES AS LEARNING SPACES - ENGINEERING STUDENTS' EXPERIENCES WITH THE CO-OP

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ABSTRACT

Many authentic learning environments in formal schooling contexts mimic elements of authentic engineering environments, yet do not afford students to experience the full complexity of a real work environment. Workplace learning is a powerful way for students to close these gaps. In this exploratory study we interviewed 11 students about their experiences in a co-op program in a Midwestern research university in the USA pre-COVID. Our qualitative study was guided by the three dimensions of learning by Illeris: personal, cognitive and social learning. We added the perspective of epistemic learning. Our preliminary findings include a variance of workplace experiences, the tensions between execution of specific tasks and the exploration and ideation of new solutions. In addition, our findings indicate that workplace engineering was demystified as issues students shared were very specific context related and not career choice related. Students also report they learned about relationship building with people from all levels of the organization, the importance of soft skills, and awareness of evaluation as a tool for reflection on the projects and their own professional development.

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1 INTRODUCTION

Many innovations in engineering education focus on implementing learning environments that are authentic and encourage students to actively engage with knowledge and practice (Strobel et al. 2013). Authentic learning environments in formal schooling contexts mimic elements of an authentic engineering environment, yet do not afford students to experience the full complexity of a real work environment (Barab and Duffy 2012). Workplace learning is a powerful way for students to close these gaps and it allows for personal and professional development (Sawchuck 2011). Some engineering programs require students to do work placements where they work on real engineering assignments, collaborate with colleagues, and get enculturated into workplace culture. There has been very little research into the wider learning experiences and outcomes in the workplace, specifically in co-op learning in engineering. Co-op is defined as a unique form of experiential learning (Kolb 1984) integrating classroom study with paid, planned and supervised work experience in the private or public sector (Garavan and Murphy 2001). In this study, we employed and extended Illeris' (2003) theory of human learning as a theoretical framework as we are interested in mapping the personal, cognitive, social and epistemic learning experiences students have in their co-ops and their perceived learning outcomes. Our research question is: What are the learning experiences of students in co-op programs and how can they be mapped to personal, cognitive, social learning and epistemic dimensions?

1.1 Literature Review

The integration of workplace learning in engineering education has become an increasingly important topic in recent years (Dehing, Jochems, and Baartman 2013). The benefits of workplace learning for engineering students include exposure to practical applications of engineering concepts, development of professional skills, and enhanced employability (Zehr and Korte 2020). Several studies have explored the effectiveness of workplace learning in engineering education. A study by Jackson (2013) found that students who participated in work-integrated learning (WIL) had a better understanding of the relevance and application of theoretical concepts in the workplace. Similarly, a study by (Sangwan and Singh 2022) showed that engineering students who participated in internships had better problem-solving skills and were better prepared for the workforce. While the literature suggests that workplace learning can provide significant benefits for engineering students, including improved understanding of theoretical concepts, development of professional skills, and increased employability, the literature does lack a mapping of the broader and comprehensive space of learning experiences of students.

1.2 Theoretical Framework

To ground this study, we chose as a starting point Illeris' (2003) theory of learning which is based on three interrelated dimensions of learning: cognitive, emotional, and social. The cognitive dimension involves acquiring new knowledge, the application of theoretical knowledge, problem solving and technical skill development (McNeill et al. 2016; Perkins and Salomon 2012). The emotional / personal dimension involves self-awareness, self-efficacy (Makki et al. 2015), motivation (Paloniemi 2006) and personal growth elements such as personal development and resilience (Sheppard et al. 2008). The social learning dimension involves collaboration (Fuller et al. 2005), teamwork (Bhavnani, Sushil, and Aldridge 2000), mentorship and professional networking (Wong et al. 2018). We extended the three-dimensional model and added *epistemic learning* as a fourth dimension. The epistemic learning dimension draws from existing work on epistemic framing (Shaffer 2004; Arastoopour et al 2016) and involves the learning of what it means to be doing engineering work, engineering practices, technologies, and workplace cultures.

2 METHODOLOGICAL FRAMEWORK

For this exploratory study, we used thematic analysis (Braun and Clarke 2012) as our methodological framework which involves identifying, analysing, and interpreting patterns and themes within data. This approach is commonly used in social sciences where researchers aim to gain an in-depth understanding of a particular phenomenon.

2.1 Population and data collection

We conducted a brief recruitment survey among all undergraduate engineering students within a research-intensive Midwestern university within the USA to determine their level of experience with co-op settings pre-COVID. All students participating in this study were part of the co-op program which included the following features: after one semester study within the university, students worked for the second semester at an industry workplace in a paid and mentored internship. The yearly structure continued for the entirety of their undergraduate program. Students in the co-op program usually worked in the same workplace throughout their undergraduate career, yet some students were placed or chose different workplaces. Students in the co-op options tended to graduate slightly later than their counterparts who studied full-time for their undergraduate studies yet had immediate work placement after graduation. From the students responding we chose 11 students who varied in their experience with the co-op program for an in-depth semi-structured interview which lasted on average 45 minutes. The study included first-year to senior students (age 18-25).

2.2 Analysis

Our process of thematic analysis involved the following stages (see Guest, MacQueen, and Namey 2011 for details): (1) Familiarization with the data: We read and familiarized ourselves with the raw data of the interview (transcript and audio). (2) Generating initial codes: We identified words, phrases, or sections of text which were relevant to the research question and created initial codes to categorize the data. (3) Developing themes: We identified patterns and connections between the codes and grouped them into broader themes or categories. (4) Reviewing and refining themes: We reviewed and refined the themes, ensuring that they accurately reflect the data and are consistent with the research question. (5) Defining and naming themes: We defined each theme and gave it a name that accurately represents its content and meaning. (6) Writing the analysis: We wrote up the analysis, providing examples from the data to illustrate each theme and highlighting the key findings. The quality of the qualitative analysis was evaluated according to Tracy (2010) by the collaborative development of the coding framework, verification of codes and their application and sample verification processes.

3 RESULTS AND DISCUSSION

3.1 Cognitive learning dimension

Within the cognitive learning dimension, we identified three separate areas of cognitive learning: Technical Skill Development, Application of Theoretical Knowledge and Problem Solving and Critical Thinking. Technical Skills Development pertains to learning and refining technical skills through hands-on experience with tools. Students mentioned how they honed their skills with mostly software in their co-ops. They report that the tool they used most often is Excel, and many students report they learned to use the Visual Basic functionality as it allowed them to do many things they would do in MATLAB in their university coursework. One student mentioned: "*There's an obsession with MATLAB at this institution. We don't use MATLAB. We use Excel.*" It was surprising for us to see that their reported use of mathematics and software tools supporting mathematical analysis was on a lower level than expected, yet this finding supports results from a previous study on the very limited use of calculus or advanced mathematics even in engineering curricula (Faulkner et al. 2020). One student mentioned explicitly that the clients they worked for all had different software packages, and learning how to work with all of these was challenging, although many packages are alike pointing to flexibility as a core professional skill (Siller et al. 2009). The Application of Theoretical Knowledge theme signals that the application of theoretical knowledge goes both ways: students can often use theoretical notions in their co-op, yet they also bring knowledge of practice to their advanced courses and are able to ask questions in class that go beyond the steady state situations that are often discussed in class which reinforces earlier findings (Eraut 2012; Brahimi et al. 2013). In some cases, students report that their co-ops informed their choice of advanced courses as they realized they missed certain knowledge while they were at their co-ops: "*My co-op experience basically kind of determined what classes I was going to take.*" This finding hasn't been previously reported in the literature.

The cognitive dimension that was mentioned most often pertains to Problem Solving and Critical Thinking. We identified two areas where Problem Solving and Critical Thinking were pertinent: Defining Constraints and Solutions, and Information Finding. Most students found that the scope and constraints of their co-op projects were ill-defined and that a major part of their project was to define their own constraints and specs confirming previous workplace research studies (Jonassen, Strobel, and Lee 2006). Students also found that the social dimension of Collaboration and Teamwork was essential for this part of problem solving as described by prior studies (Trevelyan 2019; Mora et al. 2020). Information Finding proved to be a challenge for many students. They found that a lot of relevant knowledge is tacit knowledge of colleagues and that it is paramount to talk to colleagues in all layers of the organization to gather relevant information to understand the problem within the context, to understand the constraints of their project, and to understand how any solution they come up with needs to fit in the overall processes and workflows of the organization - which mirrors findings from Paloniemi (2006). Students recognized that Information Finding has a social dimension as well as a cognitive one, which supports previous research on engineering students information behavior while in college (Leckie and Fullerton 1999). Students report that overall problem solving is what challenged them cognitively, they often use the term themselves too. It pertains to finding solutions for things they do not yet know, for trial and error, for struggling to find expertise in the organization, and identifying which concepts they learned in class are relevant for the problem at hand as similarly shown by Dixon, Raymond, and Brown (2012).

3.2 Personal learning dimension

Within the Personal Learning dimension we identified three areas of learning: Self Awareness, Self-Efficacy and Personal Growth. Self-Awareness pertains to understanding one's own strengths and weaknesses through self-reflection. Students indicated different areas of strength in the following areas (the list is a combination of all the areas mentioned): communication skills, work ethic, humbleness towards their own competence and their non-engineer colleagues, importance of knowing how they work best, ability to adapt to change, ability to have realistic ideas on how much time certain tasks take, ability to accept criticism, or an ability to communicate about issues in non-threatening ways. While students used language such as "strength", none of the students used the term "weakness". Students rather referred to challenges. Previous research on students' perceptions of readiness mention students explicitly using the term "weakness" (Martin et al. 2005) with a noticable difference that the population of the study by Martin et al. are graduates of engineering programs who had no reported workplace experience. The lack of mentioning weaknesses could also relate to a deeper concept of professional shame which is nascent in research (Secules et al. 2021)

All co-op students are asked to write a reflection report on their project and most students found it helpful as it helped them be aware of all the different activities they engaged in during the co-op which reaffirms existing research on workplace reflection (Barthakur 2022). Self-Efficacy is mentioned in relation to having to learn new skills and tools on the job through independent study, often under time pressure. It is notable that students discuss their self-efficacy on a micro and very specific technical level and not in the context of for example career self-efficacy (see Makki et al. 2015 for a framework on career self-efficacy). Students mention that co-ops have steep learning curves, as there is not much time to deliver on the projects. Semesters are 16 weeks long, and the projects are increasingly challenging. One student mentioned: "*I learned the basics at school, and then I learned some actual language by myself doing work co-op.*"

Students can commit to doing multiple co-ops with the same company and the company tends to start with easier projects, to have students work on highly complex projects in their later placements. Students appreciate this as it supports their growth. One student mentioned they started with a supply chain project and asked for a manufacturing project in the next placement, as they realized supply chain and manufacturing were strongly related, yet had very different logic to them. The Professional Growth theme reflects experiences ranging from developing better time management skills to stepping up to the plate and taking on full responsibility for their contributions, to the realisation that working is about learning new things. Students report they feel more confident after every placement and generally feel prepared to enter the labor market after their studies, because they know what to expect and know better than most classmates what they enjoy doing. In terms of self-efficacy, students did not express doubts about career choice or if they are able to overall work as an engineer. The concerns shared were more mundane and grounded in specific work context. This finding corroborates existing research that shows that workplace learning is a tool to provide confidence and demystify the profession (McEwen and Trede 2014).

3.3 Social learning dimension

In the Social Learning dimension we found experiences reflecting many elements of collaboration and teamwork. All students mentioned that collaboration, communication and problem solving are essential for finishing co-ops successfully. The importance of collaboration and teamwork emerged from all interviews and all students mentioned experiences in their social environment that had been important for progress in their projects. Projects could not be finished without input from colleagues at all stages of the project affirming previous conceptualizations of workplace learning as a form of participatory practices (Billett 2001, 2004). This partially has to do with the fact that the students found that much knowledge of importance is '*human knowledge*'. One student mentioned "*I think the model for working alone has passed. It's more a team-based environment … where [my] work is semi-autonomous.*" Within the overarching theme of Collaboration we found three sub themes: Collaboration with Different Stakeholders, Communication, and Joint Decision Making. Collaboration with Different Stakeholders reflects the importance of collaborating with operators on the factory floor, for example, the accountants, marketing professionals, and engineers from other companies who have knowledge and understanding that is paramount to fully understanding issues and understanding the overarching workflow of which the students' project is a small part (McMartin and McGourty 1999). One student mentioned that there is also a generational aspect to this: older engineers sometimes have different expectations of professional behavior and communication. Other students found that operators, accountants and marketing professionals bring unique perspectives to how problems are defined and what solutions are acceptable. One student who worked for a producer of consumer products was surprised to find how important the input of marketing was in manufacturing processes of packaging (Darling and Dannels 2003). Communication emerged as an important theme. Students mentioned the importance of asking questions and asking for input, open office spaces, open door policies and ease of communication through social media, yet also how busy some people are and that they are not always available when you need them. A third theme was Joint Decision Making. Many students experienced that important decisions were often made during team meetings where they discussed their work, or in joint decision making in meetings with their supervisors (see Halvorsen and Sarangi 2015 for different roles during team decision processes). Students were asked about any conflicts they may have encountered. Students all mentioned that in most cases, conflicts pertained to different ideas on solutions, and were usually easy to solve as everyone had an interest in solving the issue. Only a few students mentioned the importance of professional networking and mentoring. One student mentioned it in the context of understanding the importance of forging relationships with colleagues in all areas of the organisation where they work, another student mentioned they ran into a manager at a tailgating event and they were asked to connect when they were about to graduate as the manager would love *'to work something out'* with regards to future employment (see Dehing, Jochems, and Baartman 2013 who describe the development of relationship building).

3.4 Epistemic learning dimensions

Epistemic learning experiences pertain to students gaining an understanding of what it means to be doing engineering work and work in engineering contexts. As one student mentioned: "*Just having experience in general is a good thing. Because not only does it teach you how to be an engineer, it teaches you how to work* *professionally in the environment. That's not just with my company, that's with every company.*" We identified two themes: Real-world Application and Industry Exposure. Students experienced the Real-World Application of what they learned in their classes, yet were able to position their classroom learning in a bigger picture. One student said: "*[In] classrooms you're learning steady states, quasi-steady states. In the real world you're adding the safety component to it. … Also cash constraints … impose on your system and there's the people side of things. You have to learn how you adapt how that works.*" Findings of this dimension are corroborated by previous research which indicates the complexity and intricateness of workplace engineering problems (Strobel and Pan 2011). Another student shared that their project was decided on by the accountant, who established that the company was not holding up their service level agreement with a customer, which cost both parties a lot of money on a daily basis a dimension the student did not consider as part of the job before participating in the co-op experience. Students observe that many skills and formulas get meaning when they are using them to solve a real-world problem together with professionals in their co-op environment: "*That's when stuff really starts sticking for me, when I can actually kind of find the situation where I can apply it. Or it dawns on me, oh, okay, so that's why the senior engineer wanted to do it this way, is because this and this reason.*" Industry Exposure encompasses several sub themes: Workplace Culture, Professional Attitude and Problem-Solving. Students report the workplace cultures they encountered were very different from what they had expected, especially for students who did not have any engineers in their environment before they enrolled in their engineering programs (see Liu et al.'s 2020 conceptualization of this research space).

Students had expected the workplace to be rigid, individualized and that it would entail a lot of work on the factory floor. Instead students encountered team-oriented work environments that were focused on helping each other, valuing ideas and input and working with non-engineers as the norm which mirror what Darling and Dannels (2003) described as the oral nature of engineering workplace culture. Students observed that in such an environment, success is determined by their ability to solve problems, communicate effectively and their own enthusiasm and initiative to collaborate with colleagues and take charge: "*At work, the thing that's going to prevent you from solving a problem is your lack of initiative.*" To take initiative, it was important for the students to develop a Professional Attitude which students denote adapting to how colleagues communicate, dress and value each others' contributions (see Scanlon 2011 for a larger discussion of 'becoming a professional'). Professional communication was described as not using slang, learning to be precise in formulating thoughts and requests, and phrasing feedback in open-ended questions. Problem-solving in the context of epistemic learning has a different flavor than problem-solving as cognitive learning: in epistemic learning it is about reflecting on the bigger picture of problem solving and seeing it as something that is interconnected with overarching processes, that affects the organization on different levels and as an iterative practice and learning process - a finding of this study which has been addressed in existing literature on co-op or workplace learning in engineering.

4 LIMITATIONS AND FUTURE RESEARCH

The study is situated in the context of one Midwestern university in the US, which runs a specific version of a co-op program. Results from this study are impacted and are limited by the idiosyncratic program and implementation context within the university where the data have been collected. In addition, the study analyzed interviews collected from 11 students and is exploratory by nature. Interviews with different co-op programs and students at other institutes of higher education would enrich our dataset and could contribute to a wider and nuanced study of the phenomenon of workplace learning. Further research, particularly confirmatory survey research would be beneficial to study the extent of the existing dimensions among a larger body of students.

5 CONCLUSIONS AND RECOMMENDATIONS FOR PRACTICE

The research question that informed this study is: What are the learning experiences of students in co-op programs and how can they be mapped to personal, cognitive, social learning and epistemic dimensions? We found rich insights about students' learning experiences in the co-op program, where the dimensions of learning identified by Illeris (2003) showed up interconnectedly. Students shared that the social dimension, especially the communication, is essential for working in practice successfully. They also recognized that the social dimension is strongly connected with cognitive dimensions of work: setting constraints and specs for solutions. Students shared that they were surprised to find that working in engineering is a social experience, as many people provide important input for projects and that essential information is often only available as human knowledge. Students reported that they found the co-op experiences challenging in the sense that they often did not yet have the relevant knowledge, they had to identify which concepts they learned in their coursework were relevant, and they had to apply something of which they had learned only the basics. Applying basic knowledge to a real problem that exists in a context that is more complex than most examples discussed in class brings a whole new dimension to learning. In general, the students felt more confident about their ability to be successful once they enter the labor market, as they learned about workplace culture and what it takes to be a professional among professionals.

What we found striking is how little theoretical knowledge students seem to use once they are in a work environment. It is possible that students may not be aware of how much knowledge they actually apply. One student mentioned that the most important contribution of their professors is that they teach how to look at problems. Still we believe it is paramount to understand what elements of the curriculum are more and less strongly connected with professional practice and find a balance between workplace preparation and teaching the bigger concepts that are of importance to connect the dots between mathematics, science and engineering.
Overall we conclude that co-ops are rich learning environments in which dimensions of learning as identified by Illeris and extended by the epistemic dimension are present and strongly connected.

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STUDENTS' AND LECTURERS' PERCEPTIONS ON THE IMPORTANCE, TRAINING, AND ASSESSMENT OF PROFESSIONAL AND LIFELONG LEARNING COMPETENCIES

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ABSTRACT

Professional competencies and lifelong learning (LLL) are essential components for success in the engineering profession. Whilst engineering education has primarily focused on providing students with the required technical engineering competencies, new visions emphasise the importance of LLL and point towards the need for acquiring the necessary competencies for LLL during their study programme. The importance of professional and LLL competencies is clear, but what are the views of the engineering students and lecturers? In this study, a comparison is made between students' and lecturers' perceptions on professional and LLL competencies. The survey focuses on three aspects: (1) how important are the different competencies in engineering practice, (2) to what extent are they taught within the curriculum, and (3) to what extent are they assessed? In addition, lecturers were also asked to declare to what extent they possess the different professional and LLL competencies themselves. When looking at the top five competencies regarding perceived importance, extent of teaching, and extent of assessment, there are great similarities between students and lecturers. However, clear significant differences do emerge when comparing perceived importance, extent of teaching, and extent of assessment. These findings may be of interest to engineering programmes when evaluating, adapting or completely re-inventing the curriculum.

1 INTRODUCTION

1.1 The need for professional and lifelong learning competencies

In addition to technical competencies, engineering graduates today are expected to develop strong professional or non-technical engineering competencies. These engineering competencies include problem-solving skills, communication and teamwork, project management, and professional ethics (Khoo et al., 2020). New visions also emphasise the importance of lifelong learning (LLL) and point towards the need for acquiring the necessary competencies for LLL during their study programme (Zheng et al., 2017).

Employers, however, indicate that engineering graduates obtain an insufficient level of professional and lifelong learning competencies when they graduate (Markes, 2006). This raises the question as to how students and lecturers perceive these competencies. In this study, a comparison is made between student' and lecturers' perceptions of professional and LLL competencies. Before explaining the methodology, it is worth defining what is meant by professional and LLL competencies.

1.2 Defining professional and lifelong learning competencies

In line with the OECD's Learning Framework 2030 (2018), a competency is defined as a combination of knowledge, skills and attitudes.

To define professional and lifelong learning competencies, two studies, focusing on engineers, were used. Firstly, a large-scale study conducted by ASEE (American Society for Engineering Education) (2018) resulted in a framework with the required competencies for engineers. Three key groups of competencies were identified as:

- Intrapersonal Competencies: Self-Directed learning, Lifelong learning, Intellectual, Innovative, Critical Thinking, Ethical, and Conscientiousness
- Engineering Competencies: Technical/Analytical, Scientific, Mathematical, and Innovative/Creative/Design Thinking
- Interpersonal Competencies: Communication, Teamwork, Leadership, Project Management, and Social Intercultural

Secondly, a systematic literature review by (Cruz et al., 2020), focusing on engineering education, concluded that the following five lifelong learning competencies can be defined:

- Self-reflection
- Locating and scrutinising information
- Willingness, motivation and curiosity to learn
- Creating a learning plan
- Self-monitoring

2 METHODOLOGY

2.1 Sample and procedure

Data was gathered from engineering students and lecturers. As part of the [Project Acronym] project, the survey was administered to students from different study programmes at three European institutions. Students were invited through electronic messages (email, message in LMS) or live encounters (lectures, lecture breaks). in the first weeks of the second semester to fill in an online questionnaire. Lecturers were invited via mail and the link was widely spread in the three institutions and in the SEFI network. A total of 99 students and 22 lecturers responded. Participation was voluntary and free of compensation. Ethical permission was granted by the university's Social and Societal Ethics Committee (G-2022-5292-R2(MAR)).

2.2 Questionnaire

Survey respondents were asked to indicate their perceptions, via a four-point Likert scale, on the following questions:

(1) How important do you think these competencies are in engineering practice? (1 = Not important, 2= Somewhat important, 3= Important, 4= Very important or I don't know).
(2) To what extent are these competencies taught in your engineering curriculum? (1= Not taught at all, 2= Somewhat taught, 3= Taught, 4= Exhaustively taught or I don't know)
(3) To what extent are these competencies assessed in your engineering curriculum? (1= Not assessed, 2= Somewhat assessed, 3= Assessed, 4= Exhaustively assessed, NA or I don't know)
(4) Only for lecturers: How confident are you in your own ability in the following competencies? (1= Not confident at all, 2= Somewhat confident, 3= Confident, 4= Very confident or I don't know).

In order to avoid survey fatigue, it was determined that providing a list of 19 competencies (i.e., each competence noted individually) would be too onerous on survey respondents. Therefore, some competencies (i.e., self-directed & lifelong learning and leadership & project management) were paired together and 'Engineering Competencies' were omitted since these are outside the scope of this study.

2.3 Analysis

The data was analysed to compare (1) the perceived importance, extent of teaching, extent of assessment, and competency level of a range of competencies, and (2) the perceptions of lecturers and students.

For the first part of the analysis, a Friedman test is applied. The data was arranged in a long data format to analyse the data using a repeated measures procedure. In this procedure each competency is measured multiple times with a different question, namely importance, taught, assessed and for lecturers also the competency level. For each competency it is tested if there is at least one significant difference between the questions. If the Friedman test is significant ($p < .05$), pairwise comparisons are tested to determine which questions differ significantly ($p < .05$) using the Wilcoxon signed-rank test. For the second part of the analysis, Welsch tests are used to determine significant ($p < .05$) differences between lecturers and students.

3 RESULTS

3.1 Students' perceptions

Students' perceptions are included in Table 1. A mean score for perceived importance, extent of teaching, and extent of assessment is calculated for each of the different professional and lifelong learning competencies, as defined in the introduction. The table also presents the results of the pairwise comparisons. Interpretation and discussion of the results is included in the next section.

*Table 1. Students' perceptions - Mean scores are between 0 and 4. Significant differences are marked with *(p<.05), **(p<.01), ***(p<.001), ****(p<.0001)*

Students' perceptions	M			Δ		
	Importance	Taught	Assessed	ΔImp. – Tau.	ΔImp. – Ass.	ΔTau. – Ass.

Self-directed and lifelong learning	3.13	2.37	2.02	0.76****	1.11****	0.35**
Intellectual, innovative and critical thinking	3.75	2.81	2.74	0.94****	1.01****	0.07
Ethical thinking	2.82	2.49	2.23	0.33*	0.59***	0.26*
Conscientiousness	3.36	2.31	2.09	1.05****	1.27****	0.22
Communication	3.53	2.72	2.74	0.81****	0.79****	-0.02
Teamwork	3.45	2.88	2.85	0.57****	0.60****	0.03
Leadership and project management	3.29	2.47	2.46	0.82****	0.83****	0.01
Social and intercultural thinking	2.73	2.17	1.84	0.56****	0.89****	0.33***
Self-reflection	2.99	2.74	2.49	0.25	0.50***	0.25*
Locating and scrutinizing information	3.25	2.74	2.69	0.51****	0.56****	0.05
Willingness, motivation and curiosity to learn	3.31	2.17	1.99	1.14****	1.32****	0.18*
Creating a learning plan	2.71	2.13	1.86	0.58****	0.85****	0.27*
Self-monitoring	2.98	2.41	2.06	0.57****	0.92****	0.35**

3.2 Lecturers' perceptions

Table 2 presents the results of the lecturers' perceptions. A mean score for perceived importance, extent of teaching, extent of assessment, and own perceived competency is calculated for each of the different professional and lifelong learning competencies. The table also presents the results of the pairwise comparisons. Interpretation and discussion of the results is included in the next section.

*Table 2. Lecturers' perceptions - Mean scores are between 0 and 4. Significant differences are marked with *(p<.05), **(p<.01), ***(p<.001), ****(p<.0001)*

Lecturers' perceptions	M				Δ			
	Importance	Taught	Assessed	Competency	ΔImp. – Tau.	ΔImp. – Ass.	ΔTau. – Ass.	ΔImp. – Com.
Self-directed and lifelong learning	3.86	2.63	1.80	3.25	1.23***	2.06**	0.83*	0.61
Intellectual, innovative and critical thinking	3.95	2.95	2.53	3.19	1.00***	1.42**	0.42	0.76*
Ethical thinking	3.50	2.24	1.80	2.75	1.26**	1.70**	0.44	0.75
Conscientiousness	3.55	2.59	1.93	3.44	0.96**	1.62**	0.66	0.11
Communication	3.64	2.95	3.13	3.13	0.69*	0.51	-0.18	0.51
Teamwork	3.59	2.95	2.75	2.88	0.64*	0.84*	0.20	0.71
Leadership and project management	3.32	2.57	2.25	2.81	0.75*	1.07*	0.32	0.51
Social and intercultural thinking	2.86	1.90	1.54	2.44	0.96*	1.32*	0.36	0.42
Self-reflection	3.18	2.43	1.71	2.94	0.75	1.47**	0.72	0.24

Locating and scrutinizing information	3.55	2.95	2.73	3.25	0.60*	0.82*	0.22	0.3
Willingness, motivation and curiosity to learn	3.48	2.50	1.79	3.44	0.98*	1.69**	0.71	0.04
Creating a learning plan	2.67	1.80	1.36	2.53	0.87*	1.31*	0.44	0.14
Self-monitoring	3.09	2.19	1.60	2.87	0.90**	1.49**	0.59	0.22

3.3 Comparison between students' and lecturers' perceptions

For the comparison between students' and lecturers' perceptions only the significant results are included here, since all the mean scores and differences are presented in Table 1 and Table 2. For the professional competencies (1) self-directed and lifelong learning ($p<.0001$), (2) intellectual, innovative, and critical thinking ($p<.01$), and (3) ethical thinking ($p<.0001$), lecturers indicate a significant higher importance in comparison with the students. For the lifelong learning competencies (1) self-reflection ($p<.001$) and (2) creating a learning plan ($p<.05$), students indicate a significant higher presence of assessment in the curriculum.

4 DISCUSSION

4.1 Perceived importance

The professional competency *Intellectual, innovative and critical thinking* is ranked as the most important by both lecturers and students. For lecturers this is followed by *self-directed and lifelong learning, communication, teamwork, conscientiousness, and locating and scrutinizing information*. For students, the top five further consists of *communication, teamwork, conscientiousness, and willingness, motivation, and curiosity to learn*. Both communication and teamwork are also ranked as highly important competencies in two review studies focusing on engineering (Male, 2010; Cruz et al., 2020). The most recent study, (Cruz et al., 2020), also found a third important competency namely lifelong learning. The perceptions towards LLL seem different since the lecturers emphasise the importance of LLL in general, whereas the students seem to value especially the attitudinal aspect of LLL, namely willingness, motivation, and curiosity to learn. For the professional competencies (1) self-directed and lifelong learning ($p<.0001$), (2) intellectual, innovative, and critical thinking ($p<.01$), and (3) ethical thinking ($p<.0001$), lecturers indicate a significant higher importance in comparison with the students.

4.2 Extent of teaching and assessment

According to the perceptions of the lecturers, the top five competencies that are taught the most are the same competencies as the ones that are perceived as the most important ones: *intellectual, innovative and critical thinking, communication, teamwork, locating and scrutinizing information, and self-directed and lifelong learning.* The students ranked the competencies in a different order, but there is much similarity with the lecturers. The students' top five comprises: *teamwork, intellectual, innovative and critical thinking, locating and scrutinizing information, self-reflection, and communication*. Students thus selected self-reflection, which is a sub competency of lifelong learning. It could be that the lecturers' intentions to teach self-directed and lifelong learning are in fact often realized in teaching self-reflection. Lecturers perhaps view LLL in a more general and abstract level, whereas students focus on its more concrete and practical aspects.

In the assessment top five of lecturers, three interpersonal competencies are included: *communication, teamwork, leadership and project management*. The top five is further completed by *locating and scrutinizing information and intellectual, innovative and critical thinking.* Students' assessment top five consists of *teamwork, intellectual, innovative and critical thinking, communication, locating and scrutinizing information, self-reflection.* With engineering curricula becoming more student-centred to prepare students for the existing societal challenges (Hadgraft & Kolmos, 2020), assessment of the competencies mentioned above can be linked to teaching methods such as problem or project-based learning (Boelt et al., 2022; Ríos et al., 2010).

For the lifelong learning competencies (1) self-reflection ($p<.001$) and (2) creating a learning plan ($p<.05$), students indicate a significant higher presence of assessment in the curriculum compared with the views of lecturers.

4.3 Differences between importance, teaching, and assessment

For both students and lecturers, the importance of almost each competency in engineering practice is estimated to be higher than the extent to which they are taught. This is in line with the findings of (Nesterova, 2019) who stated that teaching staff recognize the importance of lifelong learning competencies, but do not consider them as primary teaching goals. Only *self-reflection* is estimated by both lecturers and students to be equally important as the extent to which it is taught and assessed. The difference between the importance in engineering practice and the extent to which it is assessed for *communication* is also not significant for lecturers.

Differences between the amount a competency is taught or assessed are limited. When a significant effect is detected, the extent to which the competency is taught is larger than the extent to which it is assessed. Students indicated this difference for *(1) self-directed and lifelong learning, (2) social and intercultural thinking, (3) willingness, motivation and curiosity to learn, (4) creating a learning plan, and (5) self-monitoring*. This includes four out of five lifelong learning competencies as well as the overarching lifelong learning competency. For lecturers this difference was only found for *self-directed and lifelong learning*.

The general trend for each competency is that the mean score is the highest for importance, followed by the extent of teaching, and the lowest mean score is for the extent of assessment. This raises the question whether this is due to the Likert scale used (e.g. very important is perhaps not exactly compatible with exhaustively assessed), or because there is indeed less assessment of the professional and lifelong learning competencies, which may be reinforced by the fact that it is difficult to assess some of these competencies (Zlatkin-Troitschanskaia et al., 2015).

Studies show that in order for students to develop these competencies, it is important to give explicit attention to them (Murdoch-Eaton & Whittle, 2012; Qanbari Qalehsari et al., 2017). Consequently, explicit training and assessment will also be important. It might also be beneficial to do the explicit talking, training, and assessment of LLL competencies in as practical terms as possible and breaking it down to the level of LLL sub-competencies. Since merely talking in the level of LLL may not give students enough to relate to the concept and hence it may remain too vague and abstract to really receive attention and effort.

5 SUMMARY AND ACKNOWLEDGMENTS

Professional competencies and lifelong learning (LLL) are essential components for success in the engineering profession. In this study, a comparison was made between student' and lecturers' perceptions on professional and LLL competencies. When looking at the top five competencies regarding perceived importance, extent of teaching, and extent of assessment, there are great similarities between students and lecturers. However, clear significant differences do emerge when comparing perceived importance, extent of teaching, and extent of assessment. These findings may be of interest to engineering programmes when evaluating, adapting or completely re-inventing the curriculum. If programmes emphasize the importance of the professional and lifelong learning competencies, it will be important to explicitly mention, train, and assess them.

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EXPLORING THE RELIABILITY, TIME EFFICIENCY AND FAIRNESS OF COMPARATIVE JUDGEMENT IN THE ADMISSION OF ARCHITECTURE STUDENTS

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ABSTRACT

It is common in architecture education to quantify the quality of assignments into grades, often done by one or two teachers using rubrics. However, this can have several downsides. It suggests an objective preciseness that is debatable for the creative assignments in the field of architecture, and the assessment is dependent on the judgement of only one or two people. Comparative judgement (CJ) offers an alternative to rubric-based assessment by applying pairwise comparison to student assignments, resulting in a ranking instead of a grade.

We used a mixed methods approach to compare the reliability, time efficiency, and fairness of CJ in the selection of students for an undergraduate architecture programme at Delft University of Technology in the Netherlands. Teachers involved in the rubric-based approach for student selection were asked to re-assess a random

selection of the assignments using CJ. Reliability and time investments for both methods were compared, and the involved assessors were asked in a focus group setting which of the two methods they perceived as more reliable and fair. Comparing rubric-based assessment to CJ is new, as previous studies have only looked at these assessment methods in isolation.

Findings indicate that CJ can be serve as a more reliable and time efficient alternative to rubric-based assessment. However, teachers still perceive rubrics as having higher reliability and fairness. Though this research is particularly relevant in the context of architecture, it contributes to wider discussions about reliable and fair assessment of creative student assignments.

1 INTRODUCTION

1.1 Research aim

In higher education, the fairness and reliability of assessment with the purpose of student selection has always been a concern, due to the impact on students' chances in life. Especially in recent years, the use of high-stake assessments has increased in both scale and range (Stobart and Eggen 2012, 1). Universities continue to search for selection methods that are reliable, time efficient, and ensure equal chances for students of dispersed backgrounds, which is no easy task, especially when the judgement of human assessors is involved.

To select students for admission, prospective students complete an assignment to show their mastery of the required skills and competencies. It is common in education to quantify the quality of the assignment into grades, often through the use of rubrics. Such a way of grading student assignments by one or two teachers has several downsides. First, assessment tasks standardised to ensure fairness, resulting in a suboptimal validity (Pollitt 2004, 4-5). Second, grading (more authentic) open-ended tasks requires a lot of time, as it is impossible to anticipate all answers that students could give and capture those in a comprehensive rubric. And, even with a rubric, the judgement underlying grading comes intuitively (Brooks 2012, 68). Third, the assessment becomes highly dependent on the judgement of one or two assessors, decreasing the reliability of grades due to the biases that assessors carry (Malouff and Thorsteinsson 2016, 249). A possible solution to these shortcomings, based on the assumption that people are better at using their professional judgement for comparing two assignments than reliably assigning a score to a single, isolated assignment, is pairwise comparative judgement (CJ). The current study aims to explore whether comparative judgement could serve as a fair and reliable method for student selection by comparing it to rubric-based assessment.

1.2 Research outline

In this study, we explore the fairness and reliability of CJ in the selection process of prospective students to the undergrad programme Architecture, Urbanism and Building Sciences (AUBS) at Delft University of Technology. Especially in this field, assessment is highly (inter)subjective. This case study compares the official procedure of selecting prospective students for assessment with the use of a rubric to a pilot assessment with CJ. We first review the theoretical background for CJ. Then, section 3 explains our mixed methods approach. In section 4 and 5 we present and discuss the results of our exploration, as well as the potential of CJ as an assessment method to be used in the context of architecture and beyond.

2 THEORETICAL BACKGROUND

2.1 Construct validity of comparative judgement

Substantiation for the appropriateness of using CJ in education can be found in existing literature. For instance, in a secondary education setting, a high construct validity was achieved with CJ. One of the main findings was that CJ privileged scientific understanding, whereas conventional grading methods favoured recall of facts. This finding supports the notion that CJ is suitable for assessing higher order skills. In the same study, however, the downside of CJ was found to be an increased rather than reduced workload for assessors (McMahon and Jones 2015, 380-2).

A similar study showed there being multiple ‘types’ of assessors, but differences in rankings compiled by these distinct types of assessors are small. All of the four types emphasised argumentation and structure in their judgement of academic writing, confirming the construct validity of the resulting ranking (Lesterhuis et al. 2022, 127-9). In practice this means that increasing the number of assessors adds extra criteria taken into account in assessment, and minimises the impact of one assessor placing a disproportional weight on a single criterion. Such a mechanism still occurs when assessors have different definitions of ‘academic writing’ (Van Daal et al. 2019, 70).

2.2 Reliability of adaptive comparative judgement

Comparative judgement has been around since the 1920’s, when it was coined as a way to measure psychological phenomena. Its application in education remained uncommon until computers became readily available to enable the use of (adaptive) algorithms, which have decreased the workload previously associated with CJ (Pollitt 2012a, 159). The resulting method of adaptive comparative judgement (ACJ) is described as a scoring instrument involving decisions on the relative quality of students’ work through pairwise comparisons, which are configured into a ranking by an adaptive algorithm (Pollitt 2012b, 283-4). Algorithms used for ACJ select the most informative comparisons to reduce the total number of comparisons needed.

Despite the reduction in the amount of comparisons needed, recent studies have concluded that the scale separation reliability (SSR) of adaptive algorithms tends to be exaggerated (Crompvoets, Béguin and Sijstsma 2020, 336; Kimbell 2022, 1523-4). Moreover, in terms of validity, the ACJ does not outperform non-adaptive methods of CJ (Bramley and Vitello 2019, 52). In a response to these findings, Crompvoets, Béguin and Sijstsma (2020) have developed an adaptive algorithm that takes into account the uncertainty of parameters related to the works being compared. Although the algorithm reduced the standard error, it still required 20 pairwise comparisons per student work to achieve a SSR of .80, equal to the number of comparisons appropriate for non-adaptive CJ. It is therefore necessary to measure the reliability of ACJ in other ways. Suggestions are to use correlations with relevant external variables, or compare different sets of assessors (Bramley 2015, 15). The current study proposes a third alternative by comparing the ranking compiled through ACJ to a ranking by the same group of assessors using a rubric.

2.3 Perceived fairness of comparative judgement

Several studies have found that students perceive comparative judgement as being more fair, as multiple assessors evaluate their work. The perspective of the assessor is less well researched. In one study, assessors considered the ranking to be informative, and were generally curious to see whether a work they view as being of good quality indeed gets placed high up in the ranking (Van Gasse et al. 2017, 12-3).

3 METHODOLOGY

This case study makes use of a mixed methods design, where the comparison of the two assessment methods in terms of reliability and time efficiency was assessed using quantitative methods, and fairness was evaluated qualitatively.

3.1 Data collection

Data collection consisted of several steps. First, the official, rubric-based selection process was carried out with 820 prospective students. Each student submitted an assignment consisting of 2 drawings and a supporting text, which was assessed by a pair of teachers from a group of 43 in total. All pairs consisted of one teacher from the Architecture department and one from the Urbanism department. In cases where the difference between the two teachers was equal to or higher than 9 points out of 30, the coordinator of the undergrad programme stepped in as a third assessor. In total, 450 students were admitted (see the left column of *Fig. 1*).

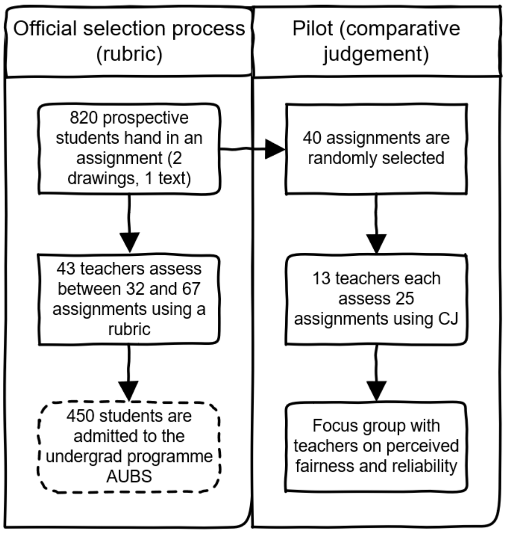

Fig. 1. Schematic overview of the selection process and data collection for the pilot.

Second, as the right column of *Fig 1.* shows, the comparative judgement was conducted as a pilot experiment with a random sample of 40 assignments selected from the pool of 820 using a random number generator. 21 of these 40 assignments were handed in by students that were admitted to the undergrad programme, and 19 belonged to students not admitted. Out of the 43 assessors involved in the rubric-based selection, 13 signed up voluntarily to each compare 25 pairs of assignments. 2 of them were from the Architecture department; 11 were from Urbanism.

Finally, fairness was evaluated in a focus group session. The assessors provided a first impression of the CJ tool and its perceived reliability and fairness anonymously. The results were then discussed in plenary. Next, the two rankings were shown next to each other and the assessors were asked which they perceived as more reliable. They did not know which raking resulted from either rubric-based or CJ assessment. The input from the focus group was summarised based on notes and observations.

3.2 Data analysis

To determine the inter-rater reliability of the rubric-based assessment, the intraclass correlation coefficient (icc) was calculated. For CJ, the subset of 40 random assignments was uploaded by the researchers into the tool 'Comproved'. The minimum number of comparisons per assessor needed to receive a reliability of .7, which is the suggested minimum for summative assessments, was calculated by using *Eq.1* (Goossens 2019, 12).

$$Comparisons\ per\ assessor = \frac{nAssignments\ \cdot 7{,}5}{nAssessors}$$

Eq. 1.

The algorithm in 'Comproved' determined which comparisons were shown to assessors. 'Comproved' also logged the time investment of each assessor, and displayed the average time per comparison. After each comparison, the tool recalculated the ranking of the assignments. When all comparisons were completed, a final ranking was produced together with its reliability coefficient.

To determine the overlap between the rankings, we computed Spearman's rank-order correlation. The same was done to determine the difference in time investment across the two methods, where the time investment for the rubric-based assessment was based on an estimation provided by the involved assessors. The time investments were grouped in cohorts of 0-4, 4-8, 8-12, etc. hours to deal with the potential inaccuracy of the estimations. For the focus group, thematic analysis was used to draw conclusions about perceived fairness and reliability.

4 RESULTS

4.1 Quantitative outcomes

Each of the 820 assignments in the official selection process was assessed by two teachers ($icc = .46$, $p < .001$), between whom the inter-rater reliability appeared as poor. For the 69 out of 820 assignments were a third assessor stepped in, the reliability was especially low (icc = -.07, p = .09).

Each assignment in the CJ subset was assessed 14 to 16 times using an adaptive algorithm. Using Spearman's rank-order correlation, the null-hypothesis is rejected, for $r_s(40) = .60, p < .001.$ This means there is significant overlap with the rubric-based ranking. However, when using a split-file Spearman's rank-order correlation separating the students who are admitted under the rubric-based assessment from those not admitted, no relationship seems to exist between the rankings resulting from the two different assessment methods ($r_s(21) = .22, p = .36$; $r_s(19) = .37, p = .11$, for students with rank 1-21 and 22-40, respectively). The reliability of the CJ ranking is .61, based on the SSR calculated by 'Comproved'.

Fig. 2 shows the two ranks per assignment. The CJ-based ranking differed from the rubric-based ranking to the extent that 4 out of 21 students admitted to the undergrad programme AUBS would not have been admitted if CJ was used for the selection process, and vice versa, 4 out of 19 would have been admitted with CJ.

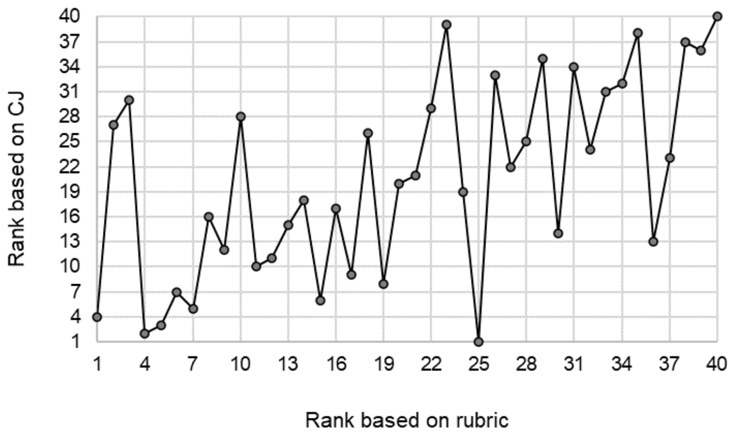

Fig. 2. Plot of each assignment's rank according to the two assessment methods.

Concerning time efficiency, assessors reported spending between 1 and 12 hours on 32 up to 67 rubric-based assessments. The average time spent on assessing 25 assignments with CJ was 27 minutes (*min = 6,4 minutes*, *max = 121,1 minutes*).

4.2 Qualitative outcomes

The opinions of the teachers concerning reliability of the different assessment methods varied. The pilot with CJ made all participating teachers question the reliability of the rubric-based assessment. Still, most regarded rubrics as more reliable than CJ, because rubrics allow for the quantification of judgement instead of basing judgement on an overall feeling. In other words, rubrics were generally considered more objective and therefore also more reliable. On top of that, many assessors did not read the supporting text in the CJ assessment and based their choice on drawings only. Because the drawings concerned different buildings, it was also difficult to compare those. Teachers who preferred CJ in terms of reliability based their opinion on the higher number of assessors per assignment in CJ, and their observation that the rubric still left too much room for interpretation.

Regarding perceived fairness, there was again a preference for rubric-based assessment, as assessors took more time for each individual assignment using that method. CJ was found to be impersonal and did not stimulate the assessors to think deeper about whether the assignment reflected a capable and suitable student. Another reason why CJ was perceived as less fair was the absence of an option to rank two assignments as equal in quality, making the ranking somewhat arbitrary.

5 SUMMARY AND ACKNOWLEDGMENTS

5.1 Discussion

Before this study, there was little to no data available to provide insight into the reliability of high-stake assessment. The use of the tool 'Comproved' allows for drawing quantitative conclusions on the ranking's reliability, whereas the reliability of rubrics is often not calculated. Having insight into an assessment's reliability allows for taking measures to increase it (such as adding more assessors to the pool, or increasing the number of comparisons per assessors in the case of CJ).

This study shows a higher reliability for CJ compared to rubric-based assignment, albeit based on different measures of reliability. Additionally, the use of CJ could lead to a reduction in workload by allowing to assess more assignments in the same amount of time. In short, because the selection process already results in a ranking, CJ could make the process more efficient. However, most teachers still perceive assessment with rubrics as more reliable and fair. It therefore difficult to conclude based on this study that CJ improves the fairness of the selection process.

5.2 Limitations

First and foremost, the limited number of participating teachers prevented us from being able to replicate the entire ranking of 820 assignments with CJ. Involving more assessors would also allow for reaching a higher reliability. In addition, the skewed division over the Architecture and Urbanism departments meant that disproportional weight may have been attached to aspects concerning urbanism in the CJ ranking. The limited availability of the teachers also caused some of them to disregard the texts and only focus on the drawings that were part of the assignment, which partly explains difference between the two rankings.

Concerning the use of the tool ‘Comproved’, one assessor clicked on the wrong assignment once, which could not be undone. For high-stake assessments with big student groups such as the undergrad selection process, the option to mark two assignments as equal would have been beneficial for the (perceived) reliability, too.

5.3 Suggestions for future research

To decrease the workload of teachers, it would be interesting to incorporate more senior students into the pool of assessors, as a meta-analysis found no difference in the amount of comparisons needed to reach a reliable ranking when the assessors are teachers versus peers (Verhavert et al., 2019, 555).

It would also be worthwhile to ask students about the perceived fairness of both methods, in addition to asking teachers. Alternatively, if CJ were to be implemented in the selection process, the number of appeals lodged against admission decisions could be compared across years to give an indication of perceived fairness.

Lastly, with a larger sample of assignments, it would be interesting to investigate the tipping point of admission versus refusal: which assessment method is most reliable in distinguishing between students who are just above and below the tipping point?

5.4 Conclusion

To summarise, using an adaptive comparative judgement tool such as ‘Comproved’ could increase the reliability and efficiency of high-stakes assessment. Using a rubric, inter-rater reliability appeared to be low, and the assessment was highly time consuming. Yet, concluding if CJ is also a more fair alternative to using a rubric depends on the perception of all of us involved in architecture education. This study calls for further research on student views on high-stakes assessment to arrive at a method that satisfies universities’ needs in ensuring equal chances for admission in the most reliable and time efficient way.

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A FRAMEWORK FOR INVESTIGATING EDUCATIONAL THEORIES IN ENGINEERING EDUCATION RESEARCH

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ABSTRACT

Grounding the design of educational interventions and their analysis in theory allows us to understand and interpret results of interventions and advance educational theories. Moreover, building an understanding of *which* educational theories are used and *how* they are used can build a consensus among researchers and mature the research

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in a field. In this paper, we investigate the extent to which educational theories are used to ground the design, analysis, and evaluation of learning activities in engineering education. For this purpose, we developed a coding instrument to determine: (1) which educational theories are expressed in studies investigating learning activities and interventions, and (2) the extent to which these theories inform (a) the design of an intervention and (b) the analysis of that intervention. The instrument was applied to a sample of 12 studies from an existing literature review on collaborative engineering design activities to demonstrate the relevance of the developed framework. Results reveal that most studies refer to educational theory, primarily pedagogical approaches such as project-based learning. Furthermore, half of the time, the design of learning interventions is grounded in theory, however, the evaluation of those interventions is often not connected to educational theories.

1 INTRODUCTION

Engineering Education Research (EER) is a relatively new research field that has grown significantly over the past decades (Borrego and Bernhard 2011). EER originates from the engineering field and was particularly shaped by scholars with an interest in education. As a young and interdisciplinary field, EER faces several challenges. The field's interdisciplinary nature leads to widely varying methodological approaches and reporting practices, making it difficult to accumulate findings and assess the effectiveness of educational approaches (Borrego 2007; Power 2021). Furthermore, it results in a multitude of theories which makes generalizing and reaching conclusions difficult. As a result, EER is characterized as a field with “low consensus” (Borrego 2007; Power 2021). This is challenging for engineering educators, who naturally come from a field with a high consensus (Power 2021).

To help engineering educators and advance EER, we suggest the discipline focuses on understanding the use of educational theories in EER. Since methodological choices cannot be separated from theoretical perspectives (Case and Light 2011), we specifically aim to investigate how educational theories are integrated into EER. We are interested in (1) which educational theories are expressed and reported on, and (2) the extent to which these theories inform (a) the design of an intervention and (b) the analysis of that intervention. Hence, we designed a framework to systematically analyze any body of literature within EER and related fields. Such systematic literature reviews are an essential step to a more mature research field and more consensus (Borrego et al 2014; 2015; Power 2021). Conducting literature reviews with this framework thus helps in generating conclusions on to what extent educational theories are grounded in the design, the analysis, and the evaluation of learning activities.

In this paper, we will present the framework, demonstrate how it can be used, and show that our framework is able to measure and monitor to what extent results are used to advance the existing theories. As a case study, we focus on educational theories expressed in research on collaborative engineering design education and present some of the results that were obtained during the validation and use of the instrument. Although the framework is universally applicable to the literature on educational interventions, we selected this topic as a case study as design is a core activity in the engineering domain (Dym et al. 2005). With our work, we hope to contribute to the advancement of the EER discipline.

2 WHY THIS STUDY?

Research into the use of theories in EER fields is not new. Earlier work looked into this topic from different perspectives and disciplines. Most of this literature provides insight into whether educational theories were used and which ones occurred most frequently.

An analysis of publications from the Journal of Engineering Education (JEE) between 1993-2002 revealed that less than 20% of papers used an educational theory to design or analyze curriculum, learning, or teaching (Wankat 2004). In contrast, Borrego et al. (2013) found that educational theories were mentioned regularly in team-based engineering projects, with literature on problem-based learning, globally distributed teams, active learning, learning styles, and Kolb's experiential learning cycle being the most popular. More recently, Malmi et al. (2018) analyzed 155 papers published in the European Journal of Engineering Education (EJEE) in 2009, 2010, and 2013, with the aim of investigating research processes in EER. This includes links to relevant theories and explanatory frameworks. In line with Borrego et al. (2013), they found that 72% of the papers applied some form of "explanatory framework" and, thus, they argue that the use of educational theories in the field is increasing. In total, the authors counted 128 different explanatory frameworks, which not only indicates a richness of theories but also captures a variety of theories that might be outside the scope of many researchers. Some of the most frequently mentioned frameworks include theories of learning, such as (social) constructivism, and models underlying specific types of science/engineering curricula, such as problem-based learning. It was concluded that even though most papers apply some explanatory framework, the chosen frameworks are often very specific and not connected to those frameworks that are most well-known or most firmly established, which they attribute to the young age of the EER discipline (Malmi et al. 2018).

The above-mentioned works (Malmi et al. 2018; Borrego et al. 2013; Wankat 2004) made considerable efforts to identify what (educational) theories are used in the EER discipline. Nevertheless, they do not specify how they consistently measured theories in terms of how theories are used for designing and analyzing learning activities, nor to what extent theories are used. It is therefore unknown how many papers "just mentioned" educational theories. Moreover, what is considered an educational theory differs per work or is unspecified. Similar issues are found in related, equally young disciplines such as Computing Education Research (CER). For this discipline, Malmi et al. (2014) found that 80% of CER literature (2015-2011) did not build on theoretical research from education, and nearly half of the research did not build on any theory at all, irrespective of the original discipline. Important to note is that a "loose" definition of theory was adopted, and numbers are small. The analysis did not address how theories are used specifically.

Recent efforts to investigate specific uses of learning theories in CER also looked into co-occurrences of the mentioned theories. In Szabo et al. (2019) three “communities of learning theories” were distinguished, namely, social theories, experiential theories, and theories of mind. This was further developed by Szabo and Sheard (2022), who distinguished six communities: behaviorist and cognitivist learning theories, working memory theories, social cognition theories, motivation learning theories, behaviorist and cognitivist meta-theories, and specific computing education learning theories. For the specific computing education learning theories, Szabo and Sheard (2022) further analyzed the quality of the theory connections by applying their Taxonomy of Learning Theory Connections, which investigates the extent to which theories are mentioned together. Their developed scale distinguishes between learning theories that are causally referenced, separately discussed, together discussed, critically compared, part of the analysis or design of the intervention/design of artefacts, and theory development. Although no such analysis was provided for the other communities of theories, this was the first framework we encountered to investigate deeply how educational theories are used in a discipline.

As is clear from the previous section, most frameworks focus on what educational theories are used but do not look at how the theories are used and advanced. In our framework, we distinguish between the design of a learning activity and the analysis of data. Moreover, we created a validated framework that can be applied to different disciplines and thus can be universally used. Our preliminary validation study also gives an indication of how the framework can be further used to provide insights into the embedding of educational theories in EER and related disciplines.

3 METHODOLOGY

3.1 Study design

To develop a framework to assess how articles concerning learning activities are grounded in educational theories, we used a body of literature from an existing systematic review (van Helden et al. 2023) on the implementation of collaboration in engineering design education to test and validate the framework. This systematic review followed Preferred Reporting Items for Systematic review and Meta-Analyses protocols (PRISMA) (Page et al. 2021) to select 111 studies. From these 111, we randomly selected 2x3 studies to develop and test our framework and another 12 studies for testing and the first results.

3.2 Development of the framework

The first three authors co-designed the framework in three iterations, of which an overview is presented below. The final framework and scales are presented in the next section, Table 1, and Figure 1. During the first iteration, the first author proposed an initial version of the framework based on our main research questions. Following this framework, a coder first identifies all educational theories mentioned in a paper. Next, using three scales with predefined items, the coder rates the extent to which this educational theory was embedded in (1) the background (i.e., introduction, related work), (2) the design of the intervention (i.e., methods), and (3) the analysis of the intervention (i.e., results, discussion, conclusion). The originally proposed scales were refined through discussion and incorporating suggestions from the second and third authors.

Next, the first three authors used the framework to code three randomly selected papers (Teiniker, Paar, and Lind 2011; Demara et al. 2017; Du et al. 2020). We compared our results of the coding of this first iteration, discussed disagreements, and resolved misalignments. For example, in the scale ‘embedding in background’, we initially distinguished between articles that give only a definition of a theory and articles that also provide further explanation or examples. However, the boundary between ‘definition’ and ‘additional explanation and example’ was not as clear as anticipated beforehand, hence we merged these items. We also created a binary scale for mentions of educational theories in the abstract (including title and keywords). After solving all disagreements in a similar way, three new randomly selected papers (Ardaiz-Villanueva et al. 2011; Alorda, Suenaga, and Pons 2011; Baumann 2020) were coded by the same three authors, using the new iteration of the framework.

When comparing the results of the second iteration, we found some misalignment between coders in what should be considered an educational theory. To avoid this in the future, a list was created with the most commonly mentioned educational theories in EER, taking into account prior studies. To maintain a clear and structured process, when a coder encountered a presumed educational theory that was not on our list, they consulted other coders to see if this was an additional educational theory eligible for coding. After making these changes to the framework, a total of 12 articles were selected and each coded by two coders (Akintewe et al. 2019; Clavijo and Pochiraju 2019; Greetham and Ippolito 2018; Jensen et al. 2018; Lara-Prieto et al. 2020; Mabley et al. 2020; Nolen and Koretsky 2018; Qamara et al. 2016; Tomkinson and Hutt 2012; Volpentesta et al. 2012; Heylen et al. 2010; Santoso et al. 2018). Using Cohen (Cohen 1960), the Inter-Rater Reliability (IRR) was calculated (see Table 1). On all scales, IRR was high and can be interpreted as ‘substantial’ to ‘almost perfect’. Any remaining disagreements between coders were discussed until a consensus was reached.

Table 1. Scales that are used in the framework. Theory here refers to educational theory. The Interrater Reliability (irr) is reported for the 12 papers coded.

Scale	**irr**	**0**	**1**	**2**	**3**	**4**
abstract	1.00	not mentioned	mentioned			
background	.82	not mentioned	mentioned without reference	mentioned with reference, but no additional information	mentioned with reference **+** additional definition, explanation, or example	
intervention design	.79	not mentioned	mentioned, but not explicitly connected with the design	explicitly connected with the design of intervention		
intervention analysis	.81	not mentioned	mentioned, but not explicitly connected with results of the intervention	explicitly connected with results of the intervention	practical implications with relation to the theory are derived from the results	advanced through findings

3.3 Framework and workflow

Framework. The designed framework is shown in Fig. 1. The left column lists commonly encountered educational theories. Additional educational theories found are added under 'additional educational theories'. Per paper, a coder assesses the embedding of all found theories on four aspects: (1) abstract, (2) background, (3) design of the intervention, and (4) analysis of the intervention. The developed scales (Table 1) have numerical codes that represent the extent to which an educational theory was integrated into a paper.

Workflow. The workflow of the framework consists of two phases and is visualised in Fig. 2. The first phase shows the identification of all educational theories mentioned in a paper. The second phase focuses on the extent to which educational theories are embedded in a paper.

	Lara-Prieto				Greetham				Heylen			
Learning Theories	Abstract	Rel. work	Design	Analysis	Abstract	Rel. work	Design	Analysis	Abstract	Rel. work	Design	Analysis
Cognitivism												
(Socio)-Constructivism					0	3	0	0				
Situated learning/ situated perspective												
Socio-cultural theory												
Socio-cognitive perspective												
Challenge-based learning	0	1	0	0								
Competition-based learning												
Game-based learning												
Group-based learning												
Inquiry-based learning												
Problem-based learning					0	2	0	0				
Project-based learning	0	0	1	0					1	1	0	0
Team-based learning					1	3	2	3				
Active learning	1	1	0	0	0	3	0	0				
Computer Supported Collaborative Learning												
Collaborative learning	1	1	0	0								
Cooperative learning												
Experiential learning												
Self-regulated learning												
Service learning												
Constructive alignment												
Flipped classroom					0	1	0	0				
Additional Learning Theories												
Competency based learning	0	0	0	1								

Fig. 1. Overview of the framework

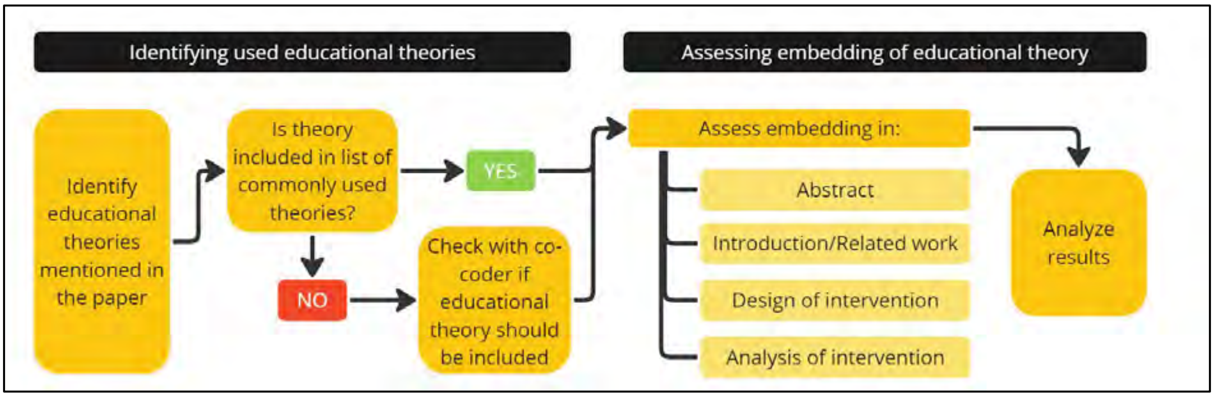

Fig. 2. Workflow: identifying & assessing embedding of educational theory

4 RESULTS

In this section, we demonstrate the relevance of the developed framework by presenting the results from the last iteration of our small subset of 12 papers, thus illustrating what type of results can be retrieved from the developed framework.

4.1 Which theories are used and to what extent?

In our sample, each article mentioned at least one educational theory. We encountered a total of 45 mentions of 22 unique educational theories. An overview of all educational theories mentioned is listed in Appendix 1. Most popular theories concern a specific pedagogical approach (e.g., project-based learning, collaborative learning), whereas philosophies on learning (theories on how people learn, such as constructivism) occur less frequently. Using the scales in our framework allowed us to make observations on the extent to which theories were integrated in different parts of a study.

Background. Theories mentioned in the introduction or related work were not always well explained. Of the 12 selected papers, 4 do not introduce any mentioned educational theories in the introduction or related work, or, if they did, no reference connected to the theory was provided (Jensen et al. 2018; Lara-Prieto et al. 2020; Nolen and Koretsky 2018; Heylen et al. 2010). Only half of the papers introduced educational theories in the background with additional definitions, explanations, examples, or references. In total, only 14 out of 45 mentions of theory are introduced with a reference and a definition, explanation, or example; 11 theories are mentioned with a reference and 10 without a reference. 10 Theories were mentioned without any introduction.

Design of intervention. Only 6 out of 12 articles ground the design of their learning activity explicitly in educational theories (Akintewe et al. 2019; Clavijo and Pochiraju 2019; Greetham and Ippolito 2018; Mabley et al. 2020; Volpentesta et al. 2012; Santoso et al. 2018). In total, eight unique theories are used to ground design choices, and four unique theories are mentioned when describing the intervention, but without making the connection with its design. Just 14 out of 45 mentions of theory (11 unique) are listed in the intervention design, of which project-based learning is the most popular (4). Furthermore, 5 out of 12 articles describe an intervention without referring to educational theory, even though their combined papers mention 31 theories (19 unique) (Jensen et al. 2018; Tomkinson and Hutt 2012; Qamara et al. 2016; Nolen and Koretsky 2018; Heylen et al. 2010).

Analysis of intervention. Two articles do not mention any educational theory during the analysis of their intervention (Qamara et al. 2016; Heylen et al. 2010). In addition, four mention theories, but never connect them to their results (Jensen et al. 2018; Clavijo and Pochiraju 2019; Lara-Prieto et al. 2020; Nolen and Koretsky 2018). Four articles make a connection between educational theory and their results (in total 8 unique theories), but no implications are derived (Clavijo and Pochiraju 2019; Jensen et al. 2018; Nolen and Koretsky 2018; Santoso et al. 2018). Finally, two papers provide practical implications related to three unique educational theories (Greetham and Ippolito 2018; Mabley et al. 2020). None of the papers advance existing theories by adding new knowledge on a theoretical level.

4.2 Observations on the use of theories in a paper

With the help of our framework, we can make several observations on the use of theories in a paper. First, theories are not uniformly nor consistently used in papers in their descriptions of background, intervention, and analysis (Appendix 1). Some theories, such as jigsaw (Akintewe et al. 2019), are mentioned consistently throughout the paper. Other theories, such as collaborative learning, project-based learning, and constructivism are primarily covered in the introduction and background.

Furthermore, occasionally, theories are mentioned as a keyword or in the abstract, but do not appear in the actual paper (Clavijo and Pochiraju 2019; Qamara et al. 2016). Additionally, 13 theories are only covered in the background of a paper, the most common being active learning (2), collaborative learning (3), constructivism (2), and project-based learning (3). Finally, 10 theories are used in the design or analysis of an intervention, but are not introduced in the background of the paper (Lara-Prieto et al. 2020; Nolen and Koretsky 2018; Tomkinson and Hutt 2012; Santoso et al. 2018).

5 DISCUSSION

In agreement with earlier studies (Malmi et al. 2018; Borrego et al. 2013), we found that educational theories are frequently mentioned. However, analysis of our sample revealed that half of the included studies do not ground the design of their intervention explicitly in educational theory. Even fewer articles list generalizable implications in relation to the educational theory during their intervention analysis. This implies that, although educational theories are mentioned, studies rarely deeply engage with these theories. The lack of connection with educational theories during the intervention analysis can be due to the type of educational theories used. Theories on pedagogical approaches were found to be the most popular. These theories, however, may be more suitable to inform the design of a learning activity than to analyze the learning triggered by that learning activity. It may be preferable to draw on theories that focus on describing and explaining behavior. Within EER, there are scientific works that can guide researchers in using this type of theories, such as (Johri et al. 2011).

Furthermore, our finding that some theories were only mentioned in the background, with or without reference, or in the abstract may indicate that these theories, such as active learning, collaborative learning, etcetera, are considered ‘well established’ and need no further explanation. In addition, it may be that these theories are only mentioned to embed the presented work in popular theorems. Sadly, by not adding references authors are denying readers necessary information.

Finally, the fact that a substantial number of theories are used in the design or analysis of an intervention while never being (properly) introduced in the background of the paper, may suggest these theories do not need further explanation and are well embedded in EER. Conversely, it may also be a sign of unawareness of the theories of the authors themselves. We have seen that in some cases, theories were only mentioned and not connected to design choices or to the results. This may suggest that our findings are in favor of the latter explanation.

The framework does have limitations. First, it is designed for identifying educational theories, which means that studies that have embedded theories from another field, even to the extent of having a solid foundation and integration in design and analysis, were not captured using this framework. Also, the framework has only been tested on a small body of literature relating to one educational topic. It needs to be more rigorously applied to more literature on more topics. Finally, our distinction between 'philosophies of learning' and 'pedagogical approaches' is preliminary, and a full classification scheme for 'type of learning theory' needs to be developed in the future.

Overall, our initial analysis of a small body of literature already highlights the advantages of using the framework to strengthen the theoretical embedding of the body of literature. The framework can be used as a diagnostic tool to analyze and quantify which theories are used in EER literature (and related fields) and how. Moreover, the framework can guide ways to find consensus in a field.

6 FUTURE WORK

Further research will extend the current analysis to the full body of literature on collaborative engineering design activities to verify trends observed in our current subset of literature. Moreover, as this framework can be generalized to any other body of literature that describes educational interventions, we aim to apply the framework to other topics relevant to the EER community, including programming education and AI education. Additionally, using the framework on a large body of literature would allow for pattern analysis regarding often recurring "paths" of an educational theory per paper. This in turn would support further evaluation of how well individual papers are embedded in educational theories, as well as how well individual theories are embedded in EER and related disciplines.

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APPENDIX 1

Table A1: All theories mentioned in the 12 coded papers, with the total number of papers mentioning them (N), the respective papers, and the number of papers that mention them per scale. The theories are categorized by embedding.

PA=Pedagodical Approach, PL=Philosohy of Learning. This classification is ***preliminary.***

Theory	Type	N	Papers	Abstract	Background	Intervention	Analysis
Project-based learning	PA	8	(Clavijo and Pochiraju 2019; Jensen et al. 2018; Lara-Prieto et al. 2020; Mabley et al. 2020; Qamara et al. 2016; Volpentesta et al. 2012; Heylen et al. 2010; Santoso et al. 2018)	4	7	4	3
Active learning	mixed	5	(Greetham and Ippolito 2018; Lara-Prieto et al. 2020; Mabley et al. 2020; Qamara et al. 2016; Santoso et al. 2018)	2	3	1	1
Collaborative learning	PA	5	(Clavijo and Pochiraju 2019; Lara-Prieto et al. 2020; Qamara et al. 2016; Volpentesta et al. 2012; Santoso et al. 2018)	4	4	1	1
Problem-based learning	PA	3	(Greetham and Ippolito 2018; Mabley et al. 2020; Tomkinson and Hutt 2012)	2	3	1	2
Flipped classroom	PA	2	(Clavijo and Pochiraju 2019; Greetham and Ippolito 2018)	1	1	1	1
Team-based learning	PA	2	(Greetham and Ippolito 2018; Qamara et al. 2016)	2	2	1	1
Jigsaw	PA	1	(Akintewe et al. 2019)	1	1	1	1
Situated learning	PL	1	(Mabley et al. 2020)	-	1	1	1
Constructivism	PL	3	(Greetham and Ippolito 2018; Mabley et al. 2020; Volpentesta et al. 2012)	-	3	1	-
Cooperative learning	PA	2	(Akintewe et al. 2019; Volpentesta et al. 2012)	1	2	1	-
Experiential learning	PA	2	(Volpentesta et al. 2012; Tomkinson and Hutt 2012)	-	1	-	1
Computer supported collaborative learning	PA	1	(Jensen et al. 2018)	-	1	-	1
Group-based learning	PA	1	(Tomkinson and Hutt 2012)	-	1	-	1
Self-regulated learning	PL	1	(Santoso et al. 2018)	-	1	-	1

Theory	Type	N	Papers	Abstract	Background	Intervention	Analysis
Case-based group discussion	PA	1	(Greetham and Ippolito 2018)	-	1	-	-
Challenge-based learning	PA	1	(Lara-Prieto et al. 2020)	-	1	-	-
Constructive alignment	other	1	(Mabley et al. 2020)	-	1	-	-
Social-cultural theory	PL	1	(Mabley et al. 2020)	-	1	-	-
Service learning	PA	1	(Akintewe et al. 2019)	1	-	1	-
Bridging epistemologies	other	1	(Nolen and Koretsky 2018)	-	-	-	1
Competency-based education	PA	1	(Lara-Prieto et al. 2020)	-	-	-	1
Knowledge building theory	PL	1	(Nolen and Koretsky 2018)	-	-	-	1

PROFESSIONAL IDENTITY OF FEMALE ENGINEERING GRADUATES: AN EXPLORATION OF IDENTITY STATUS THROUGH LIFE HISTORY RESEARCH

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ABSTRACT

The number of students entering engineering programmes is too low to meet the need for engineering graduates. Still, many leave for jobs outside the technical sector right after graduation. Professional identity is a concept that helps to explain why they stay in or leave the technical sector (Cech 2014). It is the result of the process of professional socialisation. This study uses life history research to understand the professional socialisation of engineering graduates from kindergarten age until a few years after graduation. An analysis of the life experiences of male and female engineering graduates shows differences in how they describe moments of choice, reflecting different professional identity statuses of male and female graduates.

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1 INTRODUCTION

1.1 Background

The shortage of engineering graduates in the Netherlands and other countries is an urgent issue (Monitor Techniekpact 2020, UNESCO 2021). For many societal problems, engineers are needed to contribute to the solution. To ensure that this shortage is reduced, attracting more students for engineering programmes and ensuring that engineering students who have graduated from an engineering programme do not leave the technical sector right after their graduation. A more developed professional identity can contribute to staying in the technical sector (Meijers, Kuijpers and Gundy 2013). It is the result of professional socialisation, a process in which an individual goes through experiences that develop the knowledge, skills, attitudes, habits, and modes of the professional group that one belongs to (Bragg 1976). Higher education is supposed to play an important role in providing experiences for professional socialisation, like guest lectures, internships, excursions and exposure to teachers who have experience in the field (Weidman, Twale and Stein 2001). Professional socialisation starts however long before students enter higher education. Experiences in the early childhood and at primary and secondary school also contribute to professional socialisation and as such, shape professional identity (Goodson 2008).

In this study, we analysed the socialising experiences of six female engineering graduates who stayed in engineering after their graduation and their professional identity status and compared these to the identity status of male engineering graduates. The graduates' life experiences are obtained through life history research, a form of narrative research that includes a large part of the life span of the graduates (Jessee 2019). This study focuses especially on the moments of choice in their lives: for a secondary school, for a profile at secondary school, for a degree programme and for a first job. These moments and how the graduates handle choice processes give insight into their identity statuses.

1.2 Literature review

Professional identity has been described from both a personal as well as a social perspective, the former referring to the individual development process and the stages that a person goes through (Ibarra 1999, Crocetti, et al. 2014), the latter based on the social interactions that shape professional identity (Crocetti, et al. 2014, Bartels, et al. 2010, Tajfel and Turner 1986). These two perspectives are integrated into the work of professional identity formation of Weidman, Twale and Stein (2001). The strength and the content of professional identity can be described by two behavioural indicators, as described by Marcia (1966), based on Erikson (1956). The first is called exploration and refers to the extent to which an individual explores and weighs the different identity possibilities before making decisions about goals to strive for. The second is commitment, which refers to personal investment that aligns with the choices made (Marcia 1966). These two dimensions lead to four different identity statuses: achievement, characterised by high exploration and high commitment; foreclosure, characterised by low exploration and high commitment; moratorium, characterised by high exploration and low commitment and diffusion, characterised by low exploration and low commitment. Two identity statuses were found in a previous study on the professional identity of male engineering graduates who stayed in the technical sector (van Hattum-Janssen and Endedijk 2020, Paalman 2020), The life stories that never spoke about considering options outside the technical sector at the moments of choice and a solid commitment to the technical sector, already visible from an early age, can reflect a foreclosure identity status. Those characterised by elaborate considerations at moments of choice, a tendency of indecisiveness and to keep options open as much as possible can be categorised as a moratorium identity status, with a lower commitment to the technical sector and high explication inside and outside the technical sector. At each moment of choice, a careful consideration of pros and cons is made, but coincidental life experiences may also influence the final decision. Female engineering graduates show lower levels of identification with being an engineer (Möwes, van Veelen and Endedijk 2017) and are more likely to leave the technical sector. The question is how the life experiences that result in identity statuses of male and female engineering graduates compare, as research indicates that the professional identity of female engineering graduates is related to whether they stay in or leave the technical sector (Endedijk, van Veelen and Möwes 2017).

2 METHODOLOGY

In this study, life history research was carried out by interviewing six female engineering graduates from a University of applied sciences and a research university, all found and contacted through their former course directors. They had two to six years of working experience, were between 26 and 30 years old and worked in in technical company or function.

Life history is a form of rather unstructured interviewing (Brinkman 2014). Jessee (2019) states that "(…) the life history interview should be directed by the interviewee, with the interviewee speaking in as little or as much detail as they feel is necessary to narrate those events and experiences they feel are most relevant" (p. 431). Structured or semi-structured interview schedules are therefore not appropriate for life history interviews, as they are not aimed at obtaining factual information, perceptions or opinions of the interviewees, but to engage with the subjective and intersubjective nature of the life history interview to explore the meaning of experiences from the past for the individual (Jessee 2019). The interview guide therefore consisted of an introductory question, "Tell me what you still remember about your kindergarten time at school" and only adds four further similar questions on the transition phases in their lives and the related moments of choice: the choice for a secondary school, the profile chosen at secondary school, the choice for a degree programme and the choice for a first job. The interviewees were asked to tell what they remembered about these periods and decision moments and, if possible, describe specific experiences they would recall. The interviews took place at a place the interviewees chose to ensure they would feel at ease at the chosen location and took 60 to 120 minutes.

3 RESULTS

All interviews were transcribed and analysed using Schütze's method of conducting and analysing narrative research, cited in Jovchelovitch and Bauer (2000). Pseudonyms are used for each interviewee. The indexical material is used to reconstruct the life stories. The life histories of the female engineering graduates show a number of patterns. They were good at math and physics at primary and secondary school and generally, they had high grades.

> (…) and I remember that, well, my brother was two years ahead of me and I tried over and over to do all his schoolwork although he was two years older. (Mila, Industrial Engineering and Management, Research University)

> I always wanted to be the best in class you know. (…) At the playground at school I always wanted to win, win, win. (…) And looking back I realised I was a lot smarter and more structured than the other kids in my class. (Isabella, Technical Physics, University of Applied Sciences)

> Well, I was just very conscientious. If you look at my grades, I was good at everything, eights, nines and tens on my list. (Emma, Technical Physics, Research University).

They also had rather broad interests, going beyond technical interests. They tell about a range of different hobbies and sports at primary and at secondary school and also during their time at university. Emma for instance tells about here time at secondary school.

> I did gymnastics, played the flute, and sang in a choir. I guess I found it exciting to do Greek and Latin, kind of a secret language and philosophers and to me that was exciting. (Emma, Technical Physics, Research University)

Technical interests at a young age are mentioned in all the stories.

> Yes, at the farm we had trees and ditches behind the land and corn, and we would, you know, feed the chickens and make rafts for the water and go fishing. (Isabella, Technical Physics, University of Applied Sciences)

> I always liked crafting and working on my computer, although it was still through a phone connection so less easy but I had a computer in my room. (…). And I remember once I was ill, not really ill, but with some flu and my teacher gave me and two other boys an assignment to take apart and assemble a computer as a project, make it work again. That was a lot of fun to work on. I still remember that. (Lina, Electrical Engineering, Research University).

> My dad is a real handyman and has a garage with lots of tools so we would always help him. (…) Especially when we were young, we would sometimes hold things but we were not allowed to. (…) I apparently helped to build a rabbit hutch or perhaps for a chicken, but it meant a lot of watching and holding stuff because of sharp tools, but yes I really enjoyed it. (Nicole, Technical Physics, Research University).

The first choice process, for secondary school, is described as straightforward.

> I was the third on in a row in my family, so I just went where my brothers went. (Kira, Mechanical Engineering, Research University)

> That was actually quite easy. I lived in a small village, and I had a secondary school very nearby. Just one. There I could do the first two years of senior general secondary education or

> pre-university education, so actually no choice. (Lina, Electrical Engineering, Research University)

> So not a lot of choice. You could go for one school or the other, so not a lot of choice, or further away. (…) And based on the reputation of both schools, I decided, together with my parents to go to [name town]. Well not a very difficult choice at that moment. (Isabelle, Technical Physics, University of Applied Sciences)

Later on in the interviews, the interviewees do not get back to the choices they made, except for Nicole, who made a choice that she regretted afterwards,

> That [choice for secondary school] was kind of special, as I did not want to learn. I was good at it but I thought it was too scary to do senior general secondary education. That would be too difficult, and I just did not feel like it, so I went to pre-vocational education. My twin sibling and I did not want to learn but do something with our hands and with animals, not sitting behind a desk, but from day one we felt we were so different from all other children at that school. (Nicole, Technical Physics, Research University).

She ended up at pre-university education at the end of the second year.

The choice processes for the profile at secondary school show two distinct patterns. Some of the interviewees are told that choosing for a nature and technology (N&T) profile fits them well and helps them to keep their options open.

> *And did you speak with your parents or classmates about your profile choice?*

> Yes, and also with my best friend at secondary school and what I found difficult is that all my girlfriends were going to do something else like the economic or cultural profile and I was the only one going into N&T and I feared I would end up among the nerds. But I also spoke to my math teacher and my parents. And my parents said that I needed to do what I liked most, and I will find my way. (Mila, Industrial Engineering & Management, Research University)

> It took me quite some time to land as I still remember that I went to the fourth year and had to make a profile choice. And I said to my math teacher that I wanted to do the economics and society (E&M) profile with history, economics and geography, a bit of mathematics and he looked at me and said: “No, you are not serious about this! You have to do a technical profile.” And I did not want to do anything like a technical profile, I don’t want to study anything technical later on. And he said: “If not you, then who will do a technical degree programme.” So I thought, okay, he may be right. If you are able to do it, it makes sense. You cannot go back to technical profile if you decide for the economic profile, but the other way around you can, so that is what I did. (Nicole, Technical Physics, Research University).

> My mother actually played a large role in the choices. She said with a technical profile you have more options in the future than with a non-technical profile and it became clearer to me what these profiles actually were. So, she said if you are good at math, physics and chemistry, then go for it. And she said with other profiles you have far less options afterwards. (…) So, she had those arguments and I thought, well that is also the kind of job I would like to do anyway, so we chose the N&T profile. (Isabella, Technical Physics, University of Applied Sciences)

In another life story, the N&T profile is regarded as the obvious:

> Well, I just like the technical courses the most. it was the most logical choice for me and if i would do anything else, i would have to go to senior general secondary education as they thought my grades were not good enough. I just liked this profile most. (Lina, Electrical Engineering, Research University)

The interviewees describe the choice process for a degree programme as a careful process that involves considering a number of mostly technical options at different institutions. Parents are mentioned as a discussion partner in this process. Peers are mentioned as being present during visits to open days, but not so much as the ones with whom the choice process is discussed.

> Eh, yeah, I talked a lot about it with them [parents] and they helped me too, well what do you really like, and we sat together and crossed out a number of options and then decided which open days to visit. (Lina, Electrical Engineering, Research University)

> So to Delft, Eindhoven and Enschede, but I also went to look at Business Studies or Econometrics and in Utrecht. (…) I went together with a group of girlfriends and sometimes we had to split up, because they would go to things like law and anthropology, and I wanted to go to the technical programmes and get a more all-round overview of what is possible. (Mila, Industrial Engineering & Management, Research University)

> In Delft, Eindhoven, so mostly technical universities as I had all kinds of flyers and brochures and had looked around a lot, also with my mother, who also wanted to come with me to help me. (Nicole, Technical Physics, Research University)

The last moment of choice that was explored is for the first job. Some respondents refer to being a woman as relevant in the selection process.

> It surprised me that so many employers actually wanted to talk to me, so what is so special, and then they said: "Well you are a woman in the technical sector and that is a big pre. But wouldn't men just want to have men? No, diversity. Those were new things that I learned that are were not obvious to me. But is was what I got used to. That I had been an active student, had been in the US for a while and so on… I had three clear advantages. I did not expect that and it did not fit with my initial self-image. (Isabella, Technical Physics, University of Applied Sciences)

> Before I graduated, I already knew where I was going to work. I was at the company days of the University and met someone who was very enthusiastic about women in a company, so diversity and said that I should come and work for them. And that person brought me in contact with someone who had a traineeship in mind for me. So, I went there and they said right away that I could start. (Electrical Engineering, Lina, Research University)

Others talk about staying at their graduation company. Another theme that appears is the broad orientation before deciding which offer to take.

Figure 1 shows the identity statuses found among male and female graduates that stayed in the technical sector.

Fig. 1. Identity statuses of the male and female interviewees (based on Marcia (1966)*)*

Looking at the four moments of choice and the experiences told by the female interviewees, the identity statuses of the Isabella, Mila, Emma, Nicole and Kira, can be characterised as having an achievement identity status, showing commitment to and remaining in the technical sector. They reflect the exploration that characterises this identity status. Their life experiences show a tendency to keep different options open, having a variety of hobbies and sports, having broad interests and having doubts at moments of choice. Lina's stories point to a foreclosure identity status, as committed to being in the technical sector, but not exploring a lot within or outside the technical sector. She knows that she wants to go for a technical profile, a technical degree programme and a technical job and the exploration activities seemed more a way of confirming a choice that was already made than really finding out what she wanted. The tinkering and technical crafting in her childhood that she tells about are comparable with the stories of the male graduates. The extensive talks she has with her parents to make sure that she makes the right choice differ from the stories of the male graduates who share stories about very obvious choice processes that were hardly or not at all discussed with others.

The male graduates that stayed in the technical sector showed a moratorium or foreclosure identity status. The absence of exploration characterises the foreclosure identity status. The moratorium identity status has a high exploration, but the commitment to the technical sector is rather low. The exploration in this case can lead to a technical as well as a non-technical outcome of one or more of the choice processes.

4 CONCLUSION

The identity statuses of female graduates are different from male graduates. The foreclosure status appears to be less outspoken in the sense that although the female graduate with this status is committed to the technical sector, and not exploring extensively, some of the activities described that can be regarded as exploring, appear to be a final confirmation of the decision made. The female graduates with an achievement identity status remain connected to the technical sector. In contrast, the male graduates that stayed in the technical sector did not depict any life experiences that would fit in this identity status.

The life histories of the female graduates that stayed in the technical sector show, in general, more deliberate and conscious choice processes than the male graduates. They do not mention the lack of examples of role models in their stories, or even the experienced difficulties to make the choices they have made. They know they want to remain in the technical sector and want to keep options open, but within the technical sector. They seem to have chosen paths that were not obvious or common, but did not describe experiences that can be regarded as suffering from being different or having a complicated time. Their experiences of not being mainstream was a constant factor in their lives. However, they do describe many life experiences that include the importance they attribute to the feedback of others on their, sometimes unusual, choices. These others may not be single role models, but could consist of a mosaic of elements from different people (Spaans, et al. 2023).

For those working on attracting more women to technical programmes, this means that the environments that these female students are in at the main moments of choice need to be more supportive. Teachers, parents, study counsellors at secondary school, friends and prospective universities seem to play a stronger role in the choice processes of female than of male graduates.

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Equal partnership between engineering education and industry – A needs analysis

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ABSTRACT

One of the aims of the TALENTS-project is to create (interdisciplinary) learning communities in which engineering professionals, students, teachers, and researchers can learn together and collaborate as equal partners, within the context of authentic challenges, starting from their individual learning goals. To what extent are partners willing to participate in this partnership and under which conditions do they consider it to have added value? We conducted individual interviews with engineering students (N=11), teachers (N=12) and professionals (N=10) about what they require to participate in the learning community, employing epistemic, spatial, instrumental, temporal, and social elements of learning environments. We also inquired which resources participants were willing to invest. Data were summarized on group level in a within-group matrix, following these elements. Next, we employed a cross-group analysis, focusing on commonalities and differences. The most striking results were found in the epistemic, social, and instrumental elements. Respondents have similar

needs when it comes to improving dialogue to formulate a challenge. However, professionals prefer to have more influence on formulating this challenge and its output, whereas teachers wish to focus on students' development. Students wish to co-create with partners and they place importance on matching students with a challenge that aligns with their educational background and personal interest. To create an environment based on equality, students need traditional roles of teachers, clients, and students to be less apparent. Ultimately, almost all respondents are willing to co-operate as equal partners in the learning community because they can see it leads to added value.

1 INTRODUCTION

One of the directions (vocational) education is heading, is to create programs that form a reflection of professional work practice. Educational organizations seek collaboration with industrial partners, such as government agencies, corporations, and research institutions, aiming to prepare students for ever-changing career possibilities. Simultaneously, professionals are asked to continuously develop to keep up with and adapt to societal developments (lifelong learning and development). Collaboration between education and professional work practice could therefore be a plausible step to bridge the gap between the two worlds, and for these worlds to beneficially contribute to their development and to solving societal challenges (Wagner et al., 2019).

As plausible as this seems, collaboration between education and professional work practice comes with challenges. Namely, each partner, educational or professional, enters this collaboration with expectations, hopes and specific perspectives. To be able to cooperate as *equal partners*, there should be room for each partner's needs. How should these cooperations function in an equal manner? What is needed in order to reach equality when starting from these different perspectives?

This study was conducted as a part of the nationally funded TALENTS innovation project which aims to develop authentic learning environments on the border of education and work practice to prepare students for their professional careers. Personal and professional development of students, teachers, and industrial partners is a central element. Participants are part of a learning community where they learn and work on an authentic challenge in an equal partnership.

In this study, an equal partnership is defined as a group of students, teachers, and professionals from various domains, that collectively develops, implements, and learns in an authentic learning environment. Equality is sought in employing and respecting each other's perspectives, needs, and expertise, meaning that one expertise is worth the same as the other as a steppingstone for working on a challenge. Moreover, each partner shares equal responsibility in the challenge. This way, traditional roles, and relationships, such as the teacher-student relationship, or the client-role, disappear to some extent and education becomes learner-centered, and each partner is a *learner* in the learning community.

An authentic learning environment (ALE) is defined as a setting that resembles real-world settings and situations in which learners learn to apply skills and knowledge that they were taught (Herrington and Herrington 2008). Moreover, by collectively working on a task in an ALE, learners acquire new knowledge. Learners engage in complex (often interdisciplinary) tasks, which are called authentic challenges, that are meaningful for their personal development and relevant in today's society. Learners solve topical problems collaboratively. Whilst collaborating, learners share and learn from each other's different (disciplinary) perspectives. As a partner of the learning community, Teachers are also seen as learners, as are other professionals. Teachers, however, also adopt the role of coach. They support, scaffold, and monitor the learning processes (Herrington and Herrington 2008).

Learning in an ALE cannot be designed, as the output of learning cannot be predefined in an authentic environment which enables learners to interact with different situations, activities and other learners (Bouw 2021; Zitter 2021). However, there are elements in an ALE that *can* be designed. Zitter (2021) defined five educational design elements, building on the work of Bouw et al. (2021): epistemic, spatial, temporal, social, and instrumental elements. These elements can be used to design educational settings on the boundary of education and work practice: so-called hybrid practice where learners can learn and work at the same time (Bouw et al. 2021). Epistemic elements refer to the task characteristics and arrangements (Zitter 2021). For instance, the manner in which the authentic challenge is formulated, who plays a role in formulating this, and the content of the task. A task refers to the whole activity solving an authentic challenge, for instance: designing a drone that supports farmers in protecting their crops (Zitter, 2021). Spatial elements refer to the spaces in which task-related working and learning take place (Zitter, 2021). Temporal elements are related to the time learners work on the task, the pace, and the schedules and deadlines they employ (Zitter, 2021). Social elements refer to the learners themselves, the roles they take on, and how these roles are filled and distributed (Zitter, 2021). Instrumental elements relate to the tools and artefacts that are needed to learn and work together in the learning environment (Zitter, 2021). Instruments can range from online platforms to communicate between different learners, to manuals and assessment portfolios, to support from staff, or specific physical supplies. These design elements are developed for the design of independent learning environments (Bouw et al., 2021). Timmerman et al. (2022) have demonstrated that these elements are applicable to multiple educational and vocational settings and domains.

The aim of the study was to determine how partners (engineering professionals, students, and teachers) in an ALE can learn from one another and collaborate as equal partners. Therefore, the following general research question is put central: To what extent are partners willing to participate in an equal partnership and under which conditions do they consider it to have added value?

2 METHODOLOGY

2.1 Research questions

We answered the general research question through the following sub-questions:

- RQ1: What wishes, requirements and ideas do respondents have regarding the design of the equal partnership within an authentic learning environment, distinguishing between epistemic, spatial, instrumental, temporal, and social elements?
- RQ2: To what extent are partners willing to invest in this partnership?
- RQ3: What are the opportunities and obstacles for cooperating in an equal partnership according to partners?

2.2 Respondents

The respondents consisted of 12 teachers of a Saxion University of Applied Sciences who were coaches in interdisciplinary student groups that also worked with industrial partners; 10 industrial partners from engineering corporations, research departments, or governmental organizations; and 11 full-time 4th year bachelor students, studying Mechanical Engineering (N=3), Technical Physics (N=2), Business Administration (N=2), Creative Business (N=1), Commercial Economics (N=1), Spatial Planning (N=1), Urban Planning N=1), or Climate and Management (N=1). All respondents were part of interdisciplinary groups. Respondents were approached via targeted e-mail invitations. 13 Industrial partners were approached, of which the response rate was 77%. 16 teachers were approached, of which the response rate was 75%. 61 students were approached, and the response rate was 18%.

2.3. Data collection and analysis

To answer the research questions individual interviews were conducted with each respondent. An interview was chosen as this would provide more in-depth information and the opportunity to ask follow-up questions. Individual interviews were chosen in order to get individual perspectives, rather than having respondents possibly being influenced by others. Individual interviews were possible because of the small respondent groups.

In the interviews, respondents' requirements to participate in the equal partnership were explored, distinguishing between epistemic, spatial, instrumental, temporal, and social elements of learning environments as initiated by Bouw et al. (2021) and elaborated on by Zitter (2021). These elements have been chosen to get a more nuanced picture of the respondents regarding the implementation of authentic learning environments

(RQ1). Next to these elements, it was inquired which resources respondents were willing to invest (RQ2) and which opportunities and obstacles respondents identified for cooperating in an equal partnership (RQ3).

Interviews lasted 45 minutes and took place online via Teams in the period between January 2022 and December 2022, due to COVID19 restrictions. After given consent, the meeting was recorded. Respondents were first given a definition of equal partnership. They were asked about their view on this matter, whether they would be willing to participate in such a partnership, and what they think the added value would be. Subsequently, questions based on the five educational design elements were asked by the interviewer. These questions focused on respondents' *experiences* in current educational settings, and their *needs* and *wishes.* Finally, questions regarding possible future participation in equal partnerships were asked, such as 'Which aspect would prevent you from participating in a learning community the most?'. After each interview, the data were partially transcribed and summarized based on the recording. Data were then coded with codes based on the elements of Zitter (2021). Three codes were added: investment, opportunities and obstacles. Following Miles and Huberman (1984) data were first summarized on group level in a within-group matrix, following these elements. Next, a cross-group analysis was employed, recording which topics were mentioned by the respondents and focusing on commonalities and differences in each element. This served as the basis for the description of the results.

3 RESULTS

The results are described, employing the elements of Zitter (2021), focusing on what needs and requirements partners have for participation (RQ1), whether partners are willing to participate in a partnership (RQ2), and what obstacles and opportunities of such a participation are (RQ3). In table 1, a short summary of partners' needs and requirements can be found.

3.1 Epistemic element

Industrial partners, teachers, and students require more dialogue in order to formulate the challenge and to make collective agreements for the implementation of the equal partnership. Industrial partners would like to play a more prominent role in formulating the challenge to maximize the relevance of the challenge and possible output for them. Teachers, on the other hand, require open and complex challenges with room for exploration for students. They indicate the development of students should be central and there should be room for students to fail. Students require challenges that are aligned with their interest and backgrounds. They prefer challenges that provide them with (new) knowledge and allow them to develop a concrete product. They value personal development and working on personal goals.

More dialogue is also needed to create desirable matches, as students' interests, or educational backgrounds do not always match well with the content of the challenge, the discipline or with the organization involved. Industrial partners point out that it is also important to find a suitable match with the teachers in terms of their expertise and the content and discipline of the challenge. They prefer teachers to complement their expertise.

3.2 Spatial element

All partners prefer a combination of working together online and working at school or at the organization. They all express a need to be flexible and to work in a place that is relevant for the specific task at hand. Teachers and industrial partners wish for a room at the university dedicated to the projects to land and to meet each other.

3.3 Temporal element

Teachers and students stress the importance of finding enough time for the start-up phase, namely, time needed to find suitable partners for the partnership and for dialogue to make collective agreements for the implementation of the equal partnership. When it comes to working hours, most partners desire flexibility. They prefer setting major deadlines, such as presentations of products, but other, smaller deadlines should be more flexible and plannable by students.

3.4 Social element

Partners are all willing to participate and invest time in the equal partnership, but not all industrial partners lay emphasis on the learning aspect of the collaboration. Some industrial partners view equal partnership as an opportunity to develop themselves or their organization in terms of lifelong learning. However, some are willing to invest if their problems are solved, if they gain extra hands to do their jobs, or if they gain inspiration from students. Students and teachers see similar opportunities in learning and working in an equal partnership. They both see it as a chance to broaden their knowledge about specific topics outside of their expertise and to expand their professional network. Teachers also want to learn in their role as coach. Students desire to co-create with industrial partners and teachers to learn from their different perspectives.

Up until now, partners often do not experience equality in partnerships they are involved in. Students view industrial partners as clients, and they are focused on satisfying them by performing well or by providing a solution or a product. This aligns with industrial partners, who focus on output as opposed to the learning process. This particular focus, and the lack of presence and involvement students experience from industrial partners, plays a part in their own focus and the extent to which students do not always experience equality. Moreover, teachers and students wonder to what extent equality is realistic within an equal partnership when teachers are not only learners but also assessors. Another factor that plays a role is that teachers see themselves and industrial partners as experts on the subject and having more life experience and different learning needs. They do not think these aspects align with equal partnership with students. Students also feel that they cannot make an equal contribution due to this difference.

To be able to accomplish equality in learning together in an equal partnership, students need traditional roles of teachers, industrial partners, and students to be less apparent. Instead of focusing on how to behave as a teacher, student or client, students require each partner to focus on their individual learning needs. This way, all partners can collaborate in an equal way. As a prerequisite, students indicated that industrial partners first need to understand the importance of learning and working together before an equal partnership can be formed.

3.5 Instrumental element

Industrial partners and teachers both desire more knowledge exchange in the form of (expert) workshops or clips for students as well as industrial partners. Industrial partners also prefer teachers to have knowledge of relevant topics. Moreover, they feel that there should be more dialogue between the industrial partner and the teacher to coordinate the project.

According to both teachers and students, assessment criteria play an important role in learning together in an equal partnership. Criteria should not be too restrictive because it is difficult to predict learning when working together on an authentic challenge in an equal partnership. In fact, it is difficult to assess whether students learned enough for their bachelor programs, according to teachers. Students find it important to learn from one another and to be given the chance to be innovative and go off the beaten track. Moreover, industrial partners see it as an obstacle that they are not involved with the assessment as they are convinced that they have enough knowledge to assess students' products.

Table 1. Summary of partners' needs: industrial partners (IP), teachers (T), and students(S)

Epistemic element	Partners
Dialogue to formulate challenge	IP, T, S
Focus on output	IP, S
Focus on development students	T, S
Dialogue to create desirable matches	IP, T, S

Temporal element	Partners
Enough time for the phase before and after the project	T, S
Flexible working hours	IP, T, S
Set major deadlines flexible small deadlines	IP, T, S

Instrumental element	Partners
Knowledge exchange	IP, T
Knowledgeable teachers	IP
Assessment criteria not too restrictive	T, S

Spatial element	Partners
Dedicated room at the university	IP, T
Hybrid locations	IP, T, S
Flexible locations	IP, T, S

Social element	Partners
Willing to learn as equal partners	IP, T, S
Learn in role as coach	T
Learn new specific knowledge	T
Wish to co-create	S
Need other partners to understand importance of learning together	S
No more strictly divided roles	S

4 DISCUSSION

Based on our research, we may conclude that true equality in partnership is not yet attained in our education, because of various obstacles that partners experience. However, based on the results we do see opportunities for growth towards this desired future. In fact, students, teachers and industrial partners are willing to participate and invest in an equal partnership as a learner, although they have different perspectives on learning. Partners have both similar *and* different needs regarding equal partnership within an ALE, the most striking differences were found in the epistemic and social elements.

An important difference between the partners is that industrial partners focus more on the output of the challenge, whereas teachers and students focus more on the development of students' skills and knowledge. Next to their own development, students also seek co-creation with industrial partners and teachers. Despite these differences, all partners agree that more dialogue is required to match partners with suitable authentic challenges and to formulate the challenge together. Dialogue is needed because there is not a one-size-fits-all approach to forming an equal partnership as authentic learning environments (in interdisciplinary groups) involve different partners from different domains and settings (Zitter 2021). More dialogue could help bridge the gap between the contrasting needs of the partners and help build an equal partnership. Also, sharing each other's expertise and formulating the challenge together stimulates learning, since these are regarded as two necessary processes in reaching synthesis, which is regarded a crucial prerequisite for successful results in interdisciplinary collaboration and learning (Boix Mansilla 2016; Repko and Szostak 2017).

Doing so, however, requires important steps to consider. Firstly, the *learning* aspect of the equal partnership could be made extra apparent to all partners to prevent them from taking on 'traditional roles'. This is in line with Timmerman et al. (2022), who found that it is important to make the added value in learning explicit for each partner. This promotes understanding of the added value of learning and working together in an equal partnership (Timmerman et al. 2022). Secondly, careful attention should be paid to matching students with teachers, industrial partners and an authentic challenge, by taking personal interests and disciplinary expertise into consideration, to ensure that all partners will be able to learn and to contribute equally. This could be done, for example, by organizing a matching event where industrial partners, students and teachers meet. Here, industrial partners could inform students and teachers about the challenge they are facing. Subsequently, students and teachers could consider if the challenge would allow them to learn and contribute from their expertise. In dialogue, partners could discuss how they would collectively take steps to solve the challenge. Then, partners could decide which challenge they want to be matched with.

Apart from more dialogue, another intervention seems crucial for teachers to not fall back to their ‘traditional role'. The fact is that teachers are both coaches *and* assessors, which prevents them from being an equal partner to students. To overcome this, these teachers could solely take on the role of a coach and have another teacher assess the students, or *all* partners could play a role in the assessment, such as in collaborative assessment where all partners determine the assessment criteria and grade (Falchikov 1986). Another way to achieve more equality in the partnership is to have all partners assessed.

As the groups of respondents was small, it would be interesting for future research to explore larger groups across different universities and perhaps other educational levels, to see whether there are similar needs when it comes to designing an equal partnership in the context of authentic challenges.

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Effects of engineering education on students' ethical attitudes

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ABSTRACT

Integrating teaching about ethics in engineering degree has challenges: Teachers focused on the degree core topics may lack the expertise to handle the ethics, and teachers with an ethics background may struggle to connect the ethics teaching to the field-specific issues. In addition, a portion of the students themselves may consider the non-core topic to be unnecessary or demotivating, which poses further challenges for the teaching. In the paper, we explore the ethical attitudes of students based on a survey conducted on information technology, electrical engineering and computer sciences students at our university.

The survey received 224 responses. We compare the attitudes of students depending on their progress in their studies and whether they have had any ethics teaching included in their studies. In addition, we discuss the students' attitudes compared to the ethical attitudes of the graduated engineers from a survey of members of a national engineering association.

As the goal is to understand how to better integrate ethics teaching into education, we also discuss the students' views on how the teaching should be integrated and if students' previous encounters with ethics teaching affect their opinion on the matter.

Conference Key areas: Sustainability and ethics. Engineering curriculum design.

Keywords: engineering ethics, ethical attitudes

1 INTRODUCTION

In digitizing societies, professionals of information technology, computer sciences or electrical engineering are going to be working with many of the core components of the society, that can range from tools that facilitate democracy to devices that monitor our homes or algorithms and artificial intelligence that decide what kind of news or entertainment we see. That lays heavy responsibility for the engineers and other professionals of the fields to be able to consider the ethical consequences of the solutions that are made.

That in turn challenges the engineering education to provide sufficient teaching that can support the future engineers. To better understand what is needed from the education, it is important to know how the current education affects the students' ethical attitudes.

Students' attitudes towards ethics teaching are also an interesting question. It is difficult to motivate a student, who has pre-decided that the topic is waste of time. To that end, we want to know what are the current opinions of students towards ethics teaching and how they think it should be included in curriculum.

In this paper, we discuss students' ethical attitudes and views towards different kinds of ethics teaching based on survey conducted to information technology, electrical engineering and computer sciences students at our university. The survey received 224 responses, of whom 46% recalled having had received ethics teaching during their studies thus far. Compared to our earlier study (Virta and Järvinen 2021) regarding graduated engineers of varying fields where 70% of respondents did not recall having ethics discussed during their studies, it is better, but still surprisingly low.

The research questions of this paper are:

1. Does the received teaching that discussed ethical issues affect their ethical attitudes?
2. How does students' progression in studies affect their ethical attitudes?
3. How ethical issues have been included in their studies and how students wish they would be included?
4. Do the ethical attitudes of students differ from the attitudes of graduated engineers?

The paper is structured as follows: Section 2 discusses background of ethics teaching. Section 3 discusses the methodology and the survey in more detail, and results are presented in section 4. Conclusion and discussion are in section 5.

2 Related work

Teaching ethics for engineers is multifaceted issue of what and how to teach and if the teaching has the desired effect. There are several ways to include the teaching into curricula. Colby and Sullivan, for example, present three main possibilities: stand-alone course, a brief discussion about ethics whenever ethical issues arise naturally during the course, or few hour-long modules to include into subject courses (Colby and Sullivan 2008). Stand-alone courses are strongly advocated by Unger, as they provide comprehensive view on ethics (Unger 2005). On the other hand, as Colby and Sullivan point out, if stand-alone courses are so called general philosophy courses that focus on ethical concepts, students may not know how to utilize that knowledge on the situations they encounter in work (Colby and Sullivan 2008). More so, Bairaktarova and Woodcock argue that ethical behavior does not always follow from ethical awareness (Bairaktarova and Woodcock 2017).

On ethical attitudes, in (Borkowski and Ugras 1992) Borkowski and Ugras discuss in context of accounting students the difference that age, experience and gender have on ethical attitudes. On engineering side, Balakrishnan and Tarlochan conducted an evaluation of near graduate students socio-ethical attitudes, noting also that students had difficulties to connect their current ethics teaching to relevant engineering questions (Balakrishnan and Tarlochan 2015).

3 METHODOLOGY

The survey was directed at students of information technology, electrical engineering and computer science at our university. It was held as an online survey and distributed via three email lists, each consisting of the target field students.

The survey contained five sections, three of them common to all respondents and two optional based on given answers. The common sections included demographic questions, the ethical attitudes question set and how ethical topics had been handled in their studies thus far. The optional sections asked if the students had encountered ethically questionable situations during studies or work. If they had, the optional sections asked for details about the situations.

Demographic questions included: Year of birth, gender, the total amount of study credits, start year of studies, the field of study, if they were studying at bachelor or masters level and how much they had field-specific work experience.

The ethical attitudes question set follows the ethical sensitivity scale by K. Tirri and P. Nokelainen (Tirri and Nokelainen 2012). Our survey used 14 questions, half of the original set, to match the earlier survey for members of a national academic engineers' association. The question selection was discussed further in (Virta and Järvinen 2020). List 3 enumerates the questions for further use in this paper. The students were asked to evaluate these claims with scale of 1-5, where five was to fully agree with the claim and one to fully disagree.

1. When I'm working on ethical problems, I consider the impact of my decisions on other people.
2. I try to consider other peoples' needs, even in situations concerning my own benefits.
3. I recognize my own bias when I take a stand on ethical issues.
4. I realize that I am tied to certain prejudices when I assess ethical issues.
5. I try to control my own prejudices when making ethical evaluations.
6. When I am resolving ethical problems, I try to take a position evolving out of my own social status.
7. I contemplate on the consequences of my actions when making ethical decisions.
8. I ponder on different alternatives when aiming at the best possible solution to an ethically problematic situation.
9. I am able to create many alternative ways to act when I face ethical problems in my life.
10. I believe there are several right solutions to ethical problems.
11. I notice that there are ethical issues involved in human interaction.
12. I see a lot of ethical problems around me.
13. I am aware of the ethical issues I face at work.
14. I am better than other people in recognizing new and current ethical problems.

The last common section queried if ethical topics had been discussed during their studies. Students could select among positive or negative options. Positive options included having participated in a dedicated course, ethics being discussed on multiple or singular course$s$ when pertinent to the course's main topic, or recalling passing mentions. Negative options included ethics not having been discussed in studies or being unsure if ethics had been discussed.

Students, who had received any kind of ethics-related teaching were also asked to explain what kind of courses, and how ethics was discussed. Lastly, the students were asked to sort

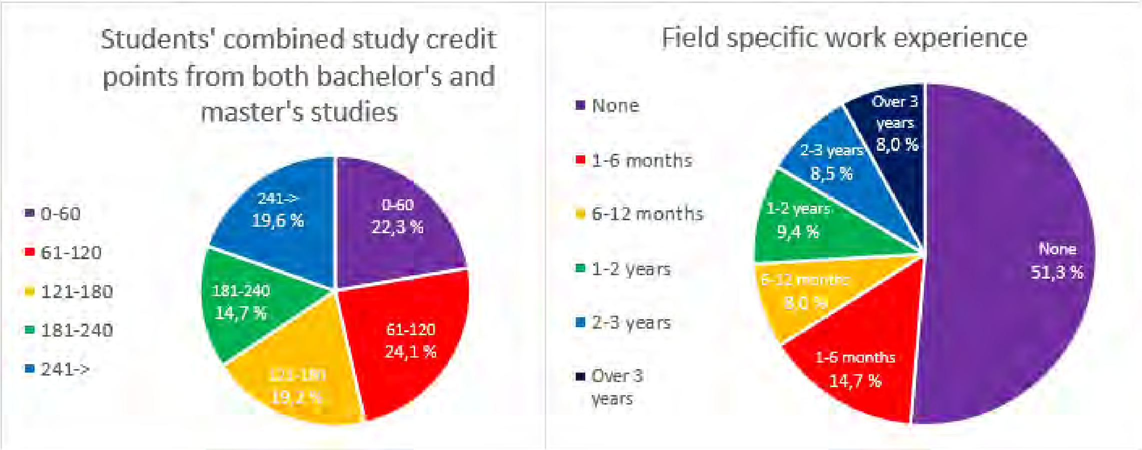

Figure 1: Overview of the study credits and field-specific work experience among respondents.

between four options for ethics teaching from their favourite to least favourite option. The options were: Separate mandatory course, Separate voluntary course, During multiple courses and combined to the core topic, and Not necessary.

Last two sections enquired if the students had encountered ethically questionable situations in either their studies or field specific work life. Students who had encountered such situations were offered possibility to elaborate about the cases. In addition, they were asked if they had felt the need to intervene, if they had done so and why they had or had not intervened.

4 RESULTS

In this chapter we discuss first the overview of respondent' background and then the effect of different factors to students' ethical attitudes are explored.

4.1 Respondents' background

The survey received responses from 224 students and of those, 64% were working on a bachelor's degree and 36% on a master's degree. The start year of studies ranged from 1989 to 2022, however 90% of the respondents had started their studies between 2015 and 2022.

Students selected their acquired study credits from five categories that correspond to the expected progression through years one to five. These categories were 0-60 study credits, 61-120sc, 121-180sc, 181-240sc and over 241 study credits. However, it should be noted that each student may have individual differences on how the accumulated credits and actual study years correspond to each other.

The progression of studies as well as field specific work experience varied between respondents, details are presented in Figure 1. Most (83%) respondents without field-specific work experience were studying for bachelor's degree with varying amount of study credits. The gender division of respondents was: 29% women, 69% men, 2% others or do not wish to answer.

4.2 Received ethics teaching

Survey charted if the respondents had received any kind of teaching in ethics during their studies. On high level, if student had picked any of the 'Positive'-options (discussed in chapter 3), they were considered to having received teaching in ethics despite any other selection they made. If they picked only 'Negative' options, they were counted as not having received ethics teaching. 46% of the students said they had received some teaching in ethics.

Unsurprisingly, the lowest study credits bracket had the least amount of students who had received ethics teaching. In further brackets, however, the increase in study credits did not automatically mean higher percentage of received ethics teaching. The differences between study fields were high, which does not look good for our engineering tracks: 76% of computer science (not an engineering track) students reported having received ethics teaching compared to 38% of information technology and 25% of electrical engineering students.

To understand what kind of ethics teaching students had received, they were also asked to shortly describe what course(s) had included ethics and how. It is important to understand if students, who had received teaching, had personally selected more ethics related courses or if the teaching was included as a part of the regular curriculum. As the students were allowed to write freely, it was not always possible to connect the response to a specific course. It was also possible that students mentioned courses from previous studies or different universities.

The single most common mention was an introductory course to computer sciences, a mandatory course in the computer sciences programme. Bit less than one in five mentioned this was their source of ethics teaching, and if counting all mentions of introductory-type courses for programmes, those were present in 23% of the descriptions.

The second largest factor was different courses in Human-Technology Interaction, mentioned in 13% of descriptions and cyber security courses (mentioned in 10%). In approximate 5-6% ball bark were mentions of machine learning courses, usability or UX-design courses and course about information technology and society. There were also singular mentions of different subject matter courses that had touched ethics. These could be, for example, courses about electronics or software engineering.

Students, who had taken specific courses in ethics were not common, but there were few mentions of for example minor studies in philosophy. Different ethics courses, which included mentions of general ethics courses but also ethics with more narrow focus such as business ethics or ethics of artificial intelligence, in combined were mentioned in 6% of the descriptions. From this we can see that ethics focused electives were not significant factor in the received ethics teaching, most students encountered it either on the mandatory introductory course or during their subject matter courses.

4.3 Ethics teaching and attitudes

To evaluate the effects of teaching on the ethical attitudes, the students were divided to five different cohorts based on the selected teaching type. If a student had picked multiple options (i.e. 'having participated in separate course on ethics' and 'ethics had been touched shortly'), the student was counted under the option that provided highest involvement with ethics.

Figure 2 gives an overview of how the attitude averages on different questions (questions 1-14) are affected depending on what kind of teaching students had received. On all the questions, students who had not received any teaching scored lower than students who had participated on separate course on ethics. Ethics discussed during multiple courses-option settles between the extremities on most questions. However, cases where ethics discussion had been encountered on one course or touched only shortly, the overall trend did not improve much compared to not having received teaching. This indicates that we cannot expect singular lecture or passing mentions to provide enough ethics teaching to see improvements in students.

4.4 Ethical attitudes in comparison to study progression or gender

To see what other factors might affect students' ethical attitudes, we also compared how the general progression in studies as well as gender reflected in the attitudes. To that purpose, first we compared the averages on the attitude scales for the five different study credit cohorts. With the fourteen questions, individual questions had different trends in how the averages

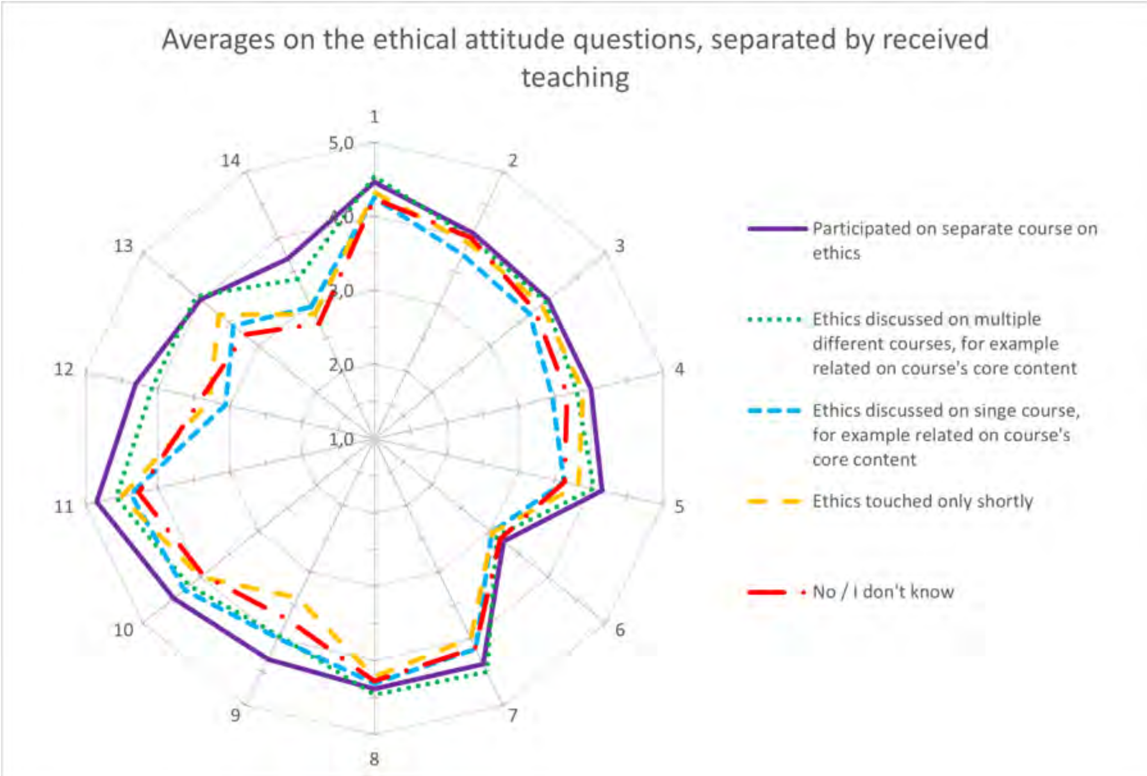

Figure 2: Overview of differences between ethical attitudes depending on the style of teaching received by student. Question numbering corresponds to list 3.

behaved between the study credit cohorts, but one trend was for the attitudes to be highest during the first year, then drop towards mid studies and raise back for the last year.

In 13 of the 14 questions, the 0-60sc cohort had higher averages than the cohort with over 240scs. Of those, in ten questions the 0-60sc cohort had highest average of all the cohorts. Not all the differences were statistically significant, but figure 3 shows the averages of the 0-60sc cohort and how much it differs from 121-180sc and over 241scs cohorts. Highlighted in green are the p-values where the difference was statistically significant.

This trend of fresh students having higher average attitudes continues even when compared to data surveyed from members of national engineering association along the study (Virta and Järvinen 2021). On majority of questions the 0-60 study credits cohort scored higher averages than the the graduated engineers already in workforce or retirement. On the questions 4, 8

Question	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Attitude averages of 0-60sc cohort	**4,58**	**4,24**	**4,04**	**3,80**	**4,08**	**3,16**	**4,52**	**4,55**	**4,02**	**4,26**	**4,60**	**3,49**	**3,37**	**2,96**
Average difference to 121-180sc cohort	0,51	0,44	0,23	0,13	0,56	0,18	0,54	0,50	0,31	0,19	0,41	0,20	-0,01	0,20
p-value	0,007	0,025	0,216	0,522	0,023	0,410	0,003	0,003	0,087	0,365	0,028	0,439	0,955	0,328
Average difference to 241sc-> cohort	0,40	0,26	0,40	0,32	0,60	0,11	0,52	0,35	0,16	0,19	0,12	0,10	-0,13	0,07
p-value	0,008	0,081	0,034	0,132	0,004	0,592	0,005	0,020	0,405	0,377	0,415	0,679	0,582	0,708

Figure 3: Attitude average differences between early and mid or late studies with highlights on p-values smaller than 0.05.

and 12 the difference was statistically significant. However, the averages from engineering association members on most questions were higher than the averages of cohort 241 and over. Difference was statistically significant on questions 1, 2, 5, and 7. From this it seems that after graduation, the attitudes get closer to the attitudes from fresher students. The question where both older student and TEK members scored higher was question 13: 'I am aware of the ethical issues I face at work.' These results are in line with findings from (Borkowski and Ugras 1992), where freshmen and juniors were found to be more justice-oriented compared to the students working on their Master of Business Administration degree.

On all fourteen questions the average for men was lower than that of women's. However, on only two questions (Questions 5 and 12) the difference was statistically significant. On questions 3, 4, 6 and 8 the difference was so small (under 0.05 points on the one-to-five scale) that the attitudes averages could be considered to be on same level.

4.5 Students' views on integrating ethics teaching in curriculum

Students were asked to rank four high level options of ethics teaching integration with scale 1 (most preferred) to 4 (least preferred). The options were: 1. Separate and mandatory course. 2. Separate but voluntary course. 3. Included in several courses, combined with core topic (CT) 4. Not necessary (to include). Table 1 gives the weighted averages for each option among all respondents, those who had received teaching and those who had not received teaching. On average, the third option was preferred by all, regardless of received teaching.

Table 1: Rank averages of ethics teaching options from 1 (favorite option) to 4 (least favorite option)

Option	All	Yes teaching	No teaching
1. Separate and mandatory course	2.87	2.69	3.03
2. Separate but voluntary course	2.04	2.19	1.91
3. Included in several courses, combined with CT	1.79	1.73	1.84
4. Not necessary	3.28	3.36	3.22

Figure 4 shows summary of how the received teaching affected the students' preferences for teaching methods. There are few places of interest. The students who had received ethics teaching selected the separate and mandatory course as their first pick (16,7%) more often than those who had not received teaching (7,4%). In addition, the students with previous ethics teaching also selected option 3 more often, resulting in situation where the option 2, which is the only one leaving the ethics teaching on voluntary basis only, was selected as the first pick by 19,6% of those who had received ethics teaching and by 32% of those who had not received ethics teaching.

Received teaching did not make difference in how large portion of students selected "Not necessary" as their first pick. Both groups selected this in slightly under 12% of answers. On the flip side, "Not necessary" option as the last pick was more popular among those who had received teaching (61,8%) than those who had not (52,5%).

In addition, students were allowed to offer other ideas on how to teach ethics and 20% of students gave suggestions. The answers were categorized based on the type of suggestion they included. One of the most popular ones was request for concrete examples, present in 23% of suggestions. Nine percent of the suggestions also included sentiments towards including experts as guest lectures or additional education for the core content lecturers. While this is minor faction of all respondents, it is still worthwhile to note that students may also evaluate if the core content lecturer is credible teacher on the subject of ethics.

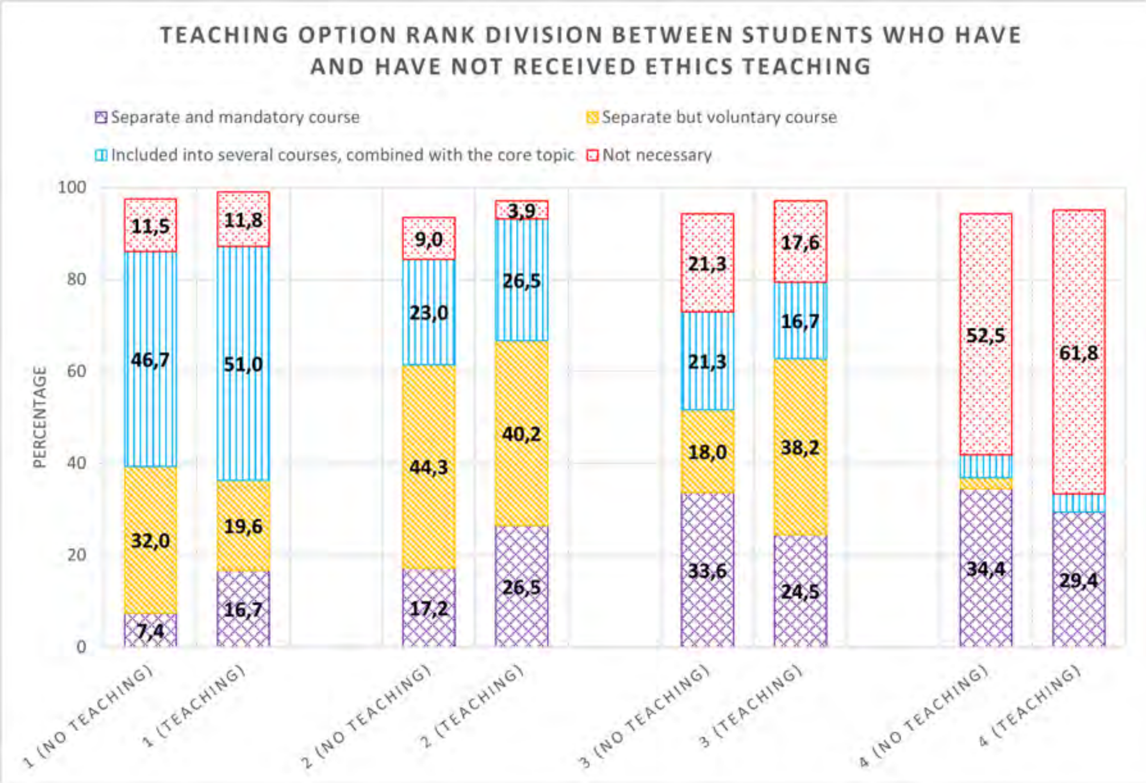

Figure 4: Overview of how students, who had received teaching and who had not, ranked different teaching options from 1 (Favorite) to 4 (Least favorite).

5 DISCUSSION

Students, who had received higher amounts of ethics teaching did, on average, score better on the ethical attitude questions compared to those who had not received teaching or had received it in slight amounts only. Merely studying in university does not guarantee improvement, as we can see from the peculiar behavior of the attitudes in relation to the study progression.

For ethics teaching in higher education, the positive finding is, that most students consider the inclusion of ethics necessary. Its integration into core topic courses was the most popular option from students' point of view. As we hypothesized, a separate and mandatory course was not very popular. It is, however, interesting to note that students who had received ethics teaching were more open to its inclusion in the curriculum, even as a mandatory part.

This opens up the question of which part of the studies the ethics should be taught and how it should be taught depending on how far the students are in their studies. Now the introductory courses were the biggest singular source of ethics teaching, but at that point, students do not yet have a comprehensive understanding of the field they are studying and the potential ethical questions that can rise within it. As the received ethics teaching did make students more receptive to further education in the topic, one possible solution could be to use the integration approach during bachelor-level studies, but provide an ethics-specific course during master's studies that could venture into general ethics as well as field-specific examples. How to balance general ethics teaching with field-specific aspects is a potential topic for future study.

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A COMMUNITY-BASED CONTEXT LEARNING APPROACH TO PROMOTING SOCIAL JUSTICE IN TEACHING ENGINEERING COMMUNICATION

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Conference Key Areas: *Embedding Sustainability and Ethics in the Curriculum; Engagement with Society and Local Communities*
Keywords: *Community-based Context Learning, Engineering Communication, Social Justice*

ABSTRACT

The research suggests a community-based context learning approach which engages students with marginalized cultural communities to investigate how technological artifacts, models or systems marginalize these cultural communities and propose for change. The goal of this approach is to increase engineering students' awareness of that engineering work can marginalize certain groups of people. The approach integrates social change to an engineering communication course and considers student learning and transformation are as important as community problems and solutions. It brings transformative learning outcomes to students, increasing their awareness of the fact that engineering is never neutral, and their engineering profession is associated with unjust social issues. With the increased awareness of social justice, students will become agents in their future workplaces to challenge and change unjust structures.

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1 INTRODUCTION

Community engagement and service-learning has been emerging as an unofficial movement in higher education in the U.S.A. It involves various learning approaches such as domestic/ international service learning, civic engagement learning, experiential learning, etc. Scholarship on community engagement and service-learning mainly focuses on positive effects on students' academic learning, increasing cultural difference awareness and intercultural competence, personal and professional development, etc.[2] However, some scholars point out that such community-engaged service learning merely emphasizes service and many students work as volunteers to do some specific tasks without attention to systems of inequality, and as a result, community engagement learning is just about offering charitable service, which is involved with no or little social justice work and even reinforces established hierarchies[3]. As these scholars realized that the charitable and depoliticized service cannot get students' attention to the root causes of social inequality and make social change, they started advocating a social justice approach to conducting community engagement and service learning. With the approach shift, students are encouraged to work as agents of social change to respond to social inequality and community issues.[4]

Social change involves "[addressing] tremendous inequalities and fundamental social challenges by creating structures and conditions that promote equality, autonomy, cooperation and sustainability."[5] Community engaged-learning practitioners who want to adopt a social justice approach must rethink their course design such as the types of service-learning projects and assignments that can challenge and change the structures perpetuating some social issues, as well as facilitating students' investigation and understanding of the root causes of them. In order to answer the above advocates' call, this research suggests a community-based context learning approach without real service. This approach maintains social justice orientation with a focus on raising engineering students' awareness of association of issues of equity with their field and profession and help them promote social change.

2 THE COMMUNITY-BASED CONTEXT LEANING APPROACH AND ITS RATIONALE

The community-based context learning approach without service is put forward in the context in which engineering scholars and modern engineering curricula espouse technical-social dualism.[6] In the book *Engineering Justice Transforming Engineering Education and Practice*, Leydens and Lucena elucidate several factors that make

[2] Eyler, Giler, Stensen and Gray, 2001.

[3] Ginwright and Cammarota, 2002.

[4] Stoecker, 2016.

[5] Langseth and Troppe, 1997, 37.

[6] Leydens and Lucena, 2018, 50.

social justice is invisible in engineering education and practice, two of which lie in engineering scholars and curricula. They reveal that "entire fields of scholars have reiterated the existence of technical-social dualism… For technical-social dualists, not only are the technical and the social separate, but they exist in a hierarchy: technical dimensions are highly valued and social ones are far less values or even irrelevant."[7] They also point out that in modern engineering curricular, engineering sciences dominate the engineering courses. By comparison, humanities, engineering design, and social science courses are far fewer included to engineering curricula. "Not only do students recognize that disparity, it becomes part of their identity as engineers."[8] Leydens and Lucena argue that engineering problem solving never occurs in a social vacuum, instead, it is conducted in a sociocultural context that shapes technical problem-solving processes and outcomes. Future more, they indicate that there are "linkages between engineering artifacts, systems, and models and issues of equity"[9]. In order to eliminate the separation of the technical and the social and increase engineering students' awareness that "engineering is never neutral", the community-based context learning approach engages students with marginalized cultural communities to investigate how technological artifacts, models or systems marginalize these cultural communities and proposed for change. This approach does not engage students with real work because an unjust issue caused by technology is always involved with several stakeholders and it cannot be resolved within one semester or through one project assignment. The goal of this approach is to increase engineering students' awareness that engineering work can marginalize certain groups of people. For example, when they develop a technological artifact for users, they can collect data from the widest range of audiences, avoiding sorting through people by skin color, gender, age, disabilities and other characteristics. Or if they identify a certain device or software excludes certain groups of people, they can use their engineering expertise to fight against such forms of exploitation, oppression and exclusion.

Unlike community-engaged service learning that emphasizes student outcomes over social change, the community-based context learning approach integrates social change to an engineering communication course and considers student learning and transformation are as important as community problems and solutions. It organizes a community-based context research project that involves engineering students in an entire research process: identify a research topic related to engineering artifacts or systems that marginalize specific cultural groups in local community, develop research questions, design methodologies, collect primary data from the specific community and secondary data from previous scholarship, do the analysis and employ their engineering expertise to make recommendations for change. Students use the previous scholarship sources, discussion, and other writing assignments and

[7] Leydens and Lucena, 2018, 50.

[8] Leydens and Lucena, 51.

[9] Leydens and Lucena, 216.

activities to have a comprehensive understanding of the issue existing not only in the community context but in a larger social structural context as well. “Such a vision is compatible with liberatory forms of pedagogy in which a goal of education is to challenge students to become knowledgeable of the social, political, and economic forces that have shaped their lives and the lives of others.”[10] Collins points out that “people experience and resist oppression on three levels: the level of personal biography; the group or community level of the cultural context created by race, class and gender; and the systemic level of social institutions.”[11] This community-based context learning approach emphasizes the three levels as potential sites to make (social) change. For example, at the personal level, this approach allows engineering students to interact with the community individuals (like having an interview or doing usability tests) to explore how a technology design denies a person’s identity through a feature such as dark skin color. Such a design seemly is not merely limited to causing personal pain, rather, it involves in race in the cultural community level. Through interacting with the community individuals, reading previous scholarship and data analysis, students will understand the real-life issues and concerns and the systematic causes resulting in them. The community-based context learning approach acknowledges how technology design can marginalize cultural groups of people and how unjust systems function in our society. This can bring students attention to social change through leveraging their engineering expertise.

Although students do not provide any real service to the community that they interact with, this approach can bring transformative learning outcomes to students, increasing their awareness of the fact that engineering is never neutral, and their engineering profession is associated with unjust social issues. Further, it skips simply doing charitable service to challenge students to investigate the root causes of inequality and use their expertise to mitigate issues and realize a more just society. In addition, social change involved in service takes time, and it will not be achieved through a course project or in a single semester. The goal of the approach is “to empower students to see themselves as agents … and create social change.” [12]As functionalist theory believes that “social change results form the accumulation of individual behaviors, is generally the result of cooperative action, and is gradual.”[13] With the increased awareness of social justice, students will become agents in their future workplaces to challenge and change unjust structures.

3 METHODOLOGY

The research was conducted in a three-credit and required course “Engineering Communication” in Cornell College of Engineering Communications Program in 2021 Fall and 2023 Spring. It obtained the approval of the university’s IRB. All the students

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[10] Rhoads, 1998, 41.

[11] Collins, 2022, 557.

[12] Forbes et al., 1999, 167.

[13] Stoecker, 2016, 80.

enrolled in the course were seniors. 43 students (17 femals and 26 males) participated in the research. In the course, there were four projects and the research was focused on Project Four that lasted 4 weeks. The students worked in groups with 4 students per group. They were required to write a 5-8 page long recommendation report and give a poster presentation. They started by identifying a problem in science/technology design or other technological artifacts and an audience/decision maker who could implement recommendations. The problem should be focused on how a certation group of people were marginalized by using the product or obtaining accurate information. The assignment included a mixture of primary and secondary research. The secondary research should mostly serve to frame the issue the students focused on. The primary research should be focused on the specific marginalized group in the local community and the students collected the information (primary date) through interacting with the marginalized group through research methods such as interviews, questionnaires, surveys, usability testing. The final deliverables included a group poster presentation, a formal proposal, and an individual reflective essay. The individual reflective essay assignment was used to assess the students' social justice awareness. In this research, the participants' final proposals and their individual reflective essays were collected for data analysis.

The research adopts a grounded theory approach to analyzing the content of the students' essays. The "inductively derived" grounded theory provides a systematic method for generating hypotheses from qualitative data. The goal of utilizing it in this research is to generate themes that can explain and demonstrate what the students have learned from the project and whether they have increased their awareness of social justice in the engineering setting. With the open coding process, I read the students' essays and marked the lines with key phrases, then grouped the similar key phrases together to generate a theme, and finally divided the themes into several categories. I repeated the process three times to improve the coding validity and reliability of the research.

4 FINDINGS AND ANALYSIS

The participants engaged with several topics related to technology and engineering settings in their proposals. Through their investigation, they interacted with various kinds of cultural groups of people (see Table 1).

Table 1. Proposal Topics and Cultural Groups Engaged

Proposal Topics	Cultural Groups Students Engaged With
Genger (in)equality in STEM majors	Female students in an engineering college
Accessibility of insulin pumps	Diabetics with visual impairment
Digital divide in U.S.A	Local residents from rural areas
Online privacy awareness of technology-illiterate users	Local illiterate technology users aged 55 on average
Non-English speakers with accents struggling with using voice assistants	Local non-English speakers from India, China mainland, and Hongkong.
Inequitable design in the Hirevue	College students of color

As this is an engineering communication course, in the students' reflective essays, the themes that emerged repeatedly were mainly focused on collaboration, communication, and ethics. Specifically, the themes consist of seven categories as follows: 1) team/individual accomplishments; 2) team/individual challenges; 3) project management; 4) effective communication; 5) diversity awareness and sensitivity; 6) ethics and social justice; 7) transfer and transformation

All the students believed that effective communication helped resolve all the challenges and issues that emerged in their teamwork. They also believed that the project management plan helped them outline the expectations and allocate tasks evenly among team members and each team member made equal contributions to the project. During interacting with the cultural groups that they worked with, they kept diversity awareness in mind and adapted themselves to communicate with the community individuals by adopting strategies such as using respectful language, active listening others' feedback and showing empathy to the individuals who were suffering from the issue. These findings demonstrate that the students have increased diversity awareness and cultural sensitivity in collaboration and communication.

Significantly, the students became to realize the importance of engineering ethics. Through the project, they identified how technology could discriminate against a certain group of people or even perpetuate existing biases and oppression in society. They leveraged their engineering expertise to propose for a change. For example, one team explored how using artificial intelligence in evaluating job applicants has unforeseen racial biases. They investigated a screening software that many companies use to sift through application materials. By interviewing their peers who were applying for jobs and internships to see what implicit bias the software has, what caused the problems and made recommendations to improve the software. One student reflected on the project and said, "I leveraged my interests in machine learning and realized that the screening software tried to be racially unbiased by not using race as an input parameter and using a training set that was 17% black while only 11% of the software users are black. Nevertheless, factors such as dispersion of features can lead to the generated model not assigning the proper weight to characteristics that are most commonly expressed by successful people of color because race is not included as an input variable in the dataset. This discovery was critical because most people who are not familiar with data science would consider including race as an input parameter giving one group an advantage, but in certain situations, it is needed for clustering that allows people of different races to be evaluated on an equal basis". Another student on the team associated the case to a higher level—the society. He said that "ethics are of the utmost importance in engineering as they ensure that the work of engineers is done in a responsible and trustworthy manner. Engineers have the power to shape the world around us, and it is their ethical duty to use this power for the benefit of society and the greater good. Our project 4 was a great example of ethics in engineering. When looking at the screening software, it was clear that their AI was biased against candidates of dark skin tones. While this isn’t a matter of life or death, it is clearly unfair and needs to be fixed.”

Another team engaged in a systematic level of social institutions. The students of the team looked into how corporations failed to take ethical considerations seriously in digital divide in the United States, which would reinforce the existing oppression. In his reflective essay, one student wrote that “[t]hrough our research project, I observed the effects of corporations failing to take ethical considerations seriously enough in the case of access to digital technology and the Internet in the United States. Certain groups struggle to obtain a level of Internet access comparable to the rest of the nation, and as a result lack many privileges held by the rest of society, often referred to as the digital divide. I also gained a new perspective on how our society tends to view progress, and how it relates to ethics. Our definition of progress is often absolute, measured by the state of the most advanced project or group, rather than by an aggregate of all groups. The ethical disadvantage from focusing on the edge of progress is that those impacted negatively or benefitting disproportionately are too often forgotten”.

Some students gained a critical awareness of technology design from working on the project. One student said, “[t]his class has definitely opened my eyes on the usability of products all around me. Before, I wouldn’t really take a second glance at anything and question whether or not the product is suitable for everyone. This is an important part of designing to ensure that your design meets all standards, including those of people outside of a target audience”. Another student pointed out problematic technology design and its solution. He said, “Through this research-based project I have learned that when most people are creating a new technology, they only test to make sure it works for them. This means that the product will most likely only work for people that are similar to that person, which is why it is important to use diverse testing sets to make sure the project can be applied to a wide range of people. Learning about issues such as this one has definitely opened my eyes up to other possible lack of ethics in technology, whether the problem is purposeful or not. More must be done to help make sure all technology is created for all people and works at the same level of quality for all”.

Some students expressed clearly that they would transfer what they have learned from the project to their future workplaces. For example, one student wrote in her reflective essay, “I learned from this project that there is still much bias and discrimination against minorities in America and that as engineers, we must make sure that whatever products or technologies we work on in the future, that they provide equal opportunities and experiences for everyone when applicable. Even for something as simple as working together on a group project, we must continue to showcase these feelings of equality and consideration for diversity when communicating with each other. These are the kinds of lessons I want to take with me when I join the workplace or if I continue to go to school as that is the kind of positive influence and contribution I want to make to the world”.

5 CONCLUSION AND LIMITATIONS

The community-based context learning approach encourages analysis, critical thinking and action. It can foster engineering students' critical consciousness of their work, allowing them to connect their profession to the lives of a specific cultural group/community and even to the entire society. Their interaction with communities makes them reflect on the impact of their personal action in maintaining and transforming social problems, becoming awareness of the systemic and structural nature of oppression. Further, the social change-oriented approach can directly get students involved in challenging and addressing structural inequality by proposing for a change with their expertise. Through the approach with a focus on social change, engineering students can look ahead and consider their own work that might lead to transforming social problems and sustainable change.

This research focuses on a small group of participants, which may not be representative. Because the research was very preliminary, I coded and analyzed the data on my own without validity from colleagues in technical and professional communication and community engagement and service learning, so the research reliability can be further improved. Future studies may focus on a larger group of participants to examine the efficacy of the approach.

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The study of the effectiveness of design-based engineering learning (DBEL): the mediating role of cognitive engagement and the moderating role of modes of engagement

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ABSTRACT

Aim: Design-based engineering learning (DBEL) offers a potentially valuable approach to engineering education, but its mechanism of action has yet to be verified by empirical studies. Accordingly, the present study aimed to establish whether DBEL produces better learning outcomes, thereby building a strong, empirically grounded case for further research into engineering education.

Methods: To build a more comprehensive model of design-based engineering learning, the variables of cognitive engagement (the mediator) and modes of engagement (the moderator) were introduced to build a theoretical process model. Questionnaires and multiple linear regression analysis were used to verify the model.

Results and discussion: All four features of DBEL (design practice, interactive reflection, knowledge integration, and circular iteration) were found to exert significant and positive effects on learning outcomes. Moreover, cognitive engagement was found to both fully and partially mediate the relationships between these features and the outcomes of engineering learning; under two different modes of engagement, the positive effects of the learning features on cognitive engagement differed significantly.

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Conclusions: The paper concluded the following: (1) a design-based learning approach can enhance engineering students' learning outcomes, (2) cognitive engagement mediates between design-based engineering learning and learning outcomes (3) a systematic mode of engagement produces better learning outcomes than a staged modes of engagement.

Conference Key Areas: Engineering Education Research

Keywords:Design-based Engineering Learning; Learning Outcomes; Cognitive Engagement; Modes of Engagement.

1 INTRODUCTION

In the early 21st century, design-based learning (DBL) was introduced to the literature (Doppelt, 2009). In DBL approaches, teachers take a bottom-up approach, posing real-world problems that encourage students to construct meaningful knowledge while completing design tasks. As they work toward a final product that meets task requirements, the students iteratively deepen their theoretical and practical topic knowledge (Goel et al., 1996; Kolodner, 2002; Mehalik and Schunn, 2010; Feiran et al., 2022). DBL is widely viewed as a model that supports innovative learning and has been combined with engineering education practice to evolve into design-based engineering learning (DBEL).

1.1 DBEL AND ENGINEERING LEARNING OUTCOMES

Eisner (1979) introduced the concept of learning outcome to denote the result of the learner's engagement in learning, including not only intentional but also unintentional outcomes. Kuh and Hu (2001) subsequently defined learning outcome as the student's ability to demonstrate evidence of competence in knowledge, skills, and values after completing a training component or full program. The outcomes of engineering learning programs include the enhancement of subject-specific knowledge, skills, and competencies (OECD, 2012; Jia, 2015; Jiang, 2015). DBEL's direct impacts on the learning outcomes of engineering students have been widely corroborated by researchers (Zhang et al., 2021; Gupta, 2022; Gutierrez-Bucheli et al., 2022). Scholars have pointed out that engineering design activities and tasks center on a cyclic, iterative process of "design–inquiry–redesign," in which learners' knowledge and abilities develop in an upward "spiral" pattern (Vincenti, 2001; Xiang, 2015, 2016). However, in the field of engineering learning, few empirical studies have examined the relationship between design-based engineering learning and learning effectiveness. To address these issues, a theoretical model of DBEL learning effectiveness was developed (see Figure 1, below). Thus, the initial hypotheses proposed in this study were as follows:

Hypothesis 1: Design-based engineering learning has a positive effect on engineering students' learning outcomes.

1.2 THE MEDIATING ROLE OF COGNITIVE ENGAGEMENT

Scholarly work has taken two perspectives on cognitive engagement: one that emphasizes the psychological involvement of learning; and another highlighting the application of learning strategies (Moliterni et al., 1990). Cognitive engagement stems from the perception that learners actively mobilize cognitive, motivational, and emotional aspects when learning, which leads to better outcomes and improves academic performance (Tinto and Pusser, 2006).

Contextual cognitivism views knowledge not as a static intellectual structure confined to the brain, but as a cognitive process that includes people, tools, other people in the environment, and knowledge-building activities (Misra, 2021). Thus, engineering science knowledge is understood as contextual, practical, and produced through collaboration (Brown et al., 1993; Streveler et al., 2008). When classrooms are characterized by clear instructional objectives, sound instructional evaluation, and effective pedagogies, learners tend to adopt deep cognitive engagement and produce better results (Ramsden et al., 2017).Based on the above analysis, this study anticipated that DBEL would provide an effective contextual learning model in which cognitive engagement plays a crucial mediating role and influences learning outcomes:

Hypothesis 2: Different aspects of design-based engineering learning positively influence engineering learning outcomes by promoting engineering students' cognitive engagement.

1.3 MODERATING ROLE OF MODES OF ENGAGEMENT

This study introduces the construct of modes of engagement to characterize design-based engineering learning in different contexts (Lina, 2022). Based on the literature, these modes of engagement are, in fact, two specific contexts in which students are engaged in design-based engineering learning, labeled here as staged and systematic engagement. The former refers to the implementation of design-based engineering learning through short-term courses and projects, which often have clear implementation goals, such as a practical project for a particular course or a graduation design. The latter denotes students' participation in two or more interrelated design-based engineering learning course modules, which occupy an important place in the four-year undergraduate engineering curriculum.

Hypothesis 3: In design-based engineering learning, systematic modes of engagement have a stronger positive impact on students' cognitive engagement than staged modes of engagement.

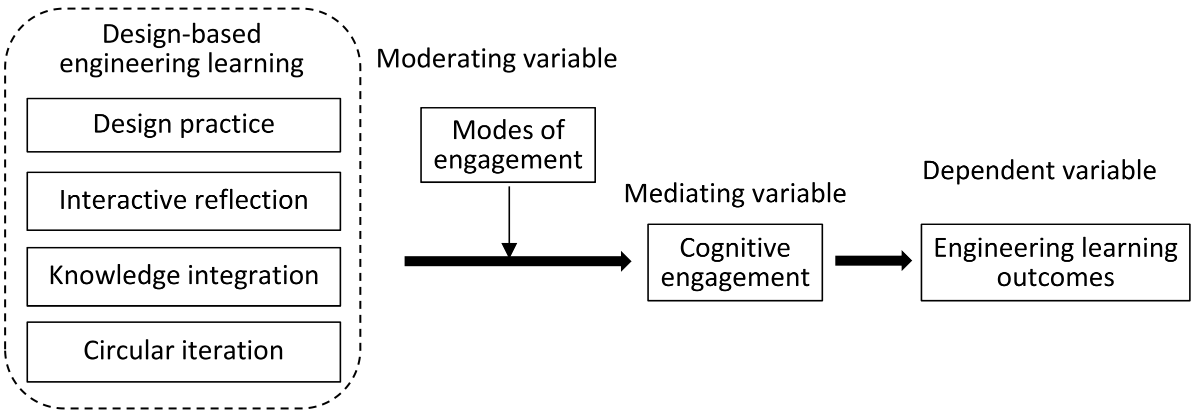

Figure. 1 Diagram of the design-based engineering learning research model

2 METHODS

2.1 DATA COLLECTION

The data for this study were collected by surveying a sample of engineering students. A total of 2590 questionnaires were distributed between September 2021 and January 2022, of which 2210 were returned, a recovery rate of 85.32%. Among these, 560 invalid questionnaires were excluded, leaving 1650 valid questionnaires, 74.7% of the total and well above the minimum rate specified for this study. All respondents had completed at least one design-based engineering learning project or course.

2.2 MEASUREMENT OF VARIABLES

The main variables measured in this study included engineering learning outcomes (the dependent variable), design-based engineering learning characteristics (the independent variable), cognitive engagement (the mediating variable), and modes of engagement (the moderating variable). The questions used to measure the dependent variable were based on earlier research carried out by Berggren et al. (2003), Pearce and Hadgraft (2011), Kolmos (2011), and Jacob and Pearce (2015). To measure the multi-dimensional features of DBEL, we referred to studies conducted by Berggren et al. (2003), Kuh (2003), Wang (2018), and Wei (2022) while the measurement questions for the mediating variable were based on work conducted by Stefanou et al. (2013) and Greene (2015). Finally, we referred to Tai et al. (2020) and Wei (2022) to set the measurement questions for the moderating variables. In addition, gender, school, grade, major, and GPA score were included in the regression model as control variables, after previous studies by Lotus Zhu (2019), Lian (2020), and Lv (2020). The questionnaire responses were measured using a 5-point Likert scale, (1 = very non-conforming, 5 = very conforming).

2.3 DESCRIPTIVE STATISTICS OF THE VARIABLES

Table 1 displays the means, standard deviations, skewness, kurtosis, and Pearson correlation coefficients of the main variables. The means ranged from 3.06 to 4.02, with standard deviations of between 0.211 and 0.987, and there were positive correlations among the variables.

Table 1. Descriptive statistics of the main variables measured by the formal questionnaire

Variables	DP	IR	KI	CI	CE	ELO	PM
DP	1						
IR	0.533**	1					
KI	0.542**	0.505**	1				
CI	0.500**	0.517**	0.536**	1			
CE	0.062*	0.061*	0.041*	0.134**	1		
ELO	0.525**	0.544**	0.530**	0.592**	0.144**	1	
PM	0.139**	0.151**	0.234**	0.147**	0.139**	0.121**	1
Mean value	3.98	4.02	3.87	3.84	3.06	3.79	0.41
Standard deviation	0.845	0.867	0.961	0.987	0.211	0.722	0.392

Note: ** $p \leq .01$ (bilateral); * $p \leq .05$ (bilateral)

3 MULTIPLE LINEAR REGRESSION

3.1 EFFECT OF DESIGN-BASED ENGINEERING LEARNING ON ENGINEERING LEARNING OUTCOMES

Table 2 reports the regression results for the linkages between various features of DBEL and engineering learning outcomes. The results show that design practice had a significant positive effect on these outcomes ($\beta = 0.365$, $p < 0.001$), as did interactive reflection ($\beta = 0.103$, $p < 0.001$), knowledge integration ($\beta = 0.198$, $p < 0.001$), and circular iteration ($\beta = 0.313$, $p < 0.001$). Therefore, hypotheses 1a, 1b, 1c, and 1d were supported.

Table 2. Regression analysis of the effect of DBEL on engineering learning outcomes

	Dependent variable: engineering learning outcomes				
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Gender	-0.004	0.005	0.008	0.010	0.006
Grade	0.037	0.012	0.003	-0.025*	-0.022*
Types of universities	0.122***	0.062***	0.044***	0.033**	0.024*
Major	0.018	-0.026	-0.015	-0.010	-0.010
GPA	0.134***	-0.006	-0.010	-0.037*	-0.001
Design practice		0.831***	0.437***	0.390***	0.365***
Interactive reflection			0.498***	0.348***	0.103***
Knowledge integration				0.228***	0.198***
Circular iteration					0.313***
Adjusted R^2	0.036	0.669	0.779	0.792	0.805
F-value	13.481	616.541	594.667	104.192	113.109
VIF value	1.070-1.197	1.070-1.199	1.070-2.372	1.071-2.482	1.071-3.072
VIF average value	1.109	1.105	1.465	1.720	1.960

Note: *p < 0.05; **p < 0.01; ***p < 0.001.

3.2 MEDIATING EFFECTS OF COGNITIVE ENGAGEMENT

3.2.1 Test for mediating effects of cognitive engagements

To decide how to test these hypothesized relationships, we consulted related studies such as Wen et al. (2022), Jiang (2022), Fang et al. (2023), and Baron and Kenny (1986). Stepwise regression and bootstrapping were used to test the mediating effect of cognitive engagement.Model 6 showed that design practice, interactive reflection, knowledge integration, and circular iteration imparted a significant positive effect on the cognitive engagement of the engineering students (see Table 3) while model 9 demonstrated that cognitive engagement had a significant positive effect on learning outcomes. Comparing models 8 and 9, it was noted that the coefficients of design practice, knowledge integration, and circular iteration with engineering students' learning outcomes changed significantly after the mediating variable of cognitive engagement was introduced while the effect of interactive reflection on the engineering students' learning outcomes became insignificant.

Table 3. Test of the mediating effects of cognitive engagement on the relationship between multidimensional learning features and engineering learning outcomes

	Dependent variable: cognitive engagement	**Dependent variable: engineering learning outcomes**		
	Mode 6	**Mode 7**	**Mode 8**	**Mode 9**
Gender	-0.024	-0.004	0.006	0.016
Grade	-0.026*	0.037	-0.022*	-0.011
Types of Universities	0.011	0.122***	0.024*	0.019
Major	0.000	0.018	-0.010	-0.010
GPA	0.046***	0.134***	-0.001	-0.017
Design practice	0.362***		0.365***	0.214***
Interactive reflection	0.116***		0.186***	0.022
Knowledge integration	0.193***		0.198***	0.150***
Circular iteration	0.308***		0.313***	0.184***
Cognitive engagement				0.419***
Adjusted R^2	0.828	0.016	0.047	0.053

F-value	123.744	5.238	13.439	14.131
VIF value	1.071-3.072	1.070-1.152	1.071-3.072	1.019-3.190
VIF average value	1.960	1.12875	1.960	1.963

Note: *p < 0.05; **p < 0.01; ***p < 0.001.

3.2.2 Bootstrap test analysis for the significance of the mediating effect

Based on the preliminary results, basic bootstrap resampling was conducted using Stata16 software to empirically analyze the mediating effects of cognitive engagements. In this study, 2000 bootstrap resampling analyses were conducted based on the 1650 samples to obtain the standard deviation, significance, and 95% confidence intervals of the direct, indirect, and total effect unstandardized path coefficients of the model path analysis. The test results are shown in Table 4.

Table 4. Results of the analysis of the bootstrap test for the significance of mediation effects

Intermediary model	**Total effect**	**Direct effect**	**Indirect effect [95%, CI]**
DBEL→CE→ELO	0.882***	0.477***	0.405***[0.317，0.503]
DP→CE→ELO	0.749***	0.242***	0.509***[0.448，0.565]
IR→CE→ELO	0.787***	0.269***	0.517***[0.437，0.594]
KI→CE→ELO	0.668***	0.206***	0.462***[0.406，0.517]
CI→CE→ELO	0.790***	0.289***	0.501***[0.422，0.583]

Note: *p < 0.05; **p < 0.01; ***p < 0.001 (N = 1650)

The investigation of the mediating role of cognitive engagement showed that its mediation of the relationship between design-based engineering learning and engineering learning outcomes was significant, with an indirect effect value of 0.405 ($p < 0.001$) and a 95% confidence interval of [0.317, 0.503]. Cognitive engagement also significantly mediated the effects of the following aspects of DBEL on engineering learning outcomes: design practice (0.509, $p < 0.001$, 95% CI [0.448, 0.565]), interactive reflection (0.517, $p < 0.001$, 95% CI [0.437, 0.594]), knowledge integration (0.462, $p < 0.001$, 95% CI [0.406, 0.517]), and circular iteration (0.501 $p < 0.001$, 95% CI [0.422, 0.583]). In summary, hypotheses 2a, 2b, 2c, and 2d were tested and all four were verified.

3.3 MODERATING EFFECT OF MODES OF ENGAGEMENT

Following Fang et al. (2022), group regression and interaction terms were then used to test the moderating effect of modes of engagement. The sample was divided into two groups according to the type of modes of engagement (systematic vs. staged), and group regressions were randomly conducted using SPSS (see Table 5).

Table 5. The moderating effects of modes of engagement and cognitive engagement in DBEL

Dependent variable: cognitive engagement	**Model 10**	**Model 11**	**Model 12**
	Staged engagement	**Systematic engagement**	
Gender	0.032	0.022	0.006
Grade	-0.023	-0.045	-0.022
Types of Universities	0.023	0.012	0.021

Major	-0.054	0.005	-0.010
GPA	0.017	0.017	-0.010
Design practice (DP)	0.159**	0.450***	0.368***
Interactive reflection (IR)	0.097*	0.104*	0.190***
Knowledge integration (KI)	0.152	0.115*	0.117***
Circular iteration (CI)	0.587***	0.308***	0.306***
DP×PM			0.049*
IR×PM			0.081**
KI×PM			0.005
CI×PM			0.024
Adjusted R^2	0.772	0.871	0.906
F-value	218.262***	388.540***	577.597***
VIF value	1.070-3.123	1.070-2.868	1.070-2.973
VIF average value	1.967	1.816	1.903

Note：*p < 0.05；**p < 0.01；***p < 0.001.

In model 10 (systematic engagement in design-based learning), design practice, interactive reflection, knowledge integration, and circular iteration had significant positive effects on engineering students' learning outcomes. However, in model 11 (the staged engagement model), only the first three of these had significant positive effects on learning outcomes while the effect of knowledge integration was insignificant.

Finally, the systematic and staged engagement modes were set to 0 and 1, respectively and their interactions with design practice, interactive reflection, knowledge integration, and cyclic iteration were tested. The results showed positive and significant interaction terms for the mode of engagement and the two variables of design practice ($\beta = 0.049$, $p < 0.05$) and interactive reflection ($\beta = 0.081$, $p < 0.001$). However, the corresponding terms for knowledge integration and circular iteration were not significant ($\beta = 0.005$, $p > 0.05$; $\beta = 0.024$, $p > 0.05$).

4 MAIN FINDINGS

4.1 DESIGN-BASED ENGINEERING LEARNING EFFECTIVELY ENHANCES ENGINEERING STUDENTS' LEARNING OUTCOMES

This study empirically tested the significant positive effects of four learning characteristics on learning outcomes through multiple regression analysis. First, the test results showed a significant positive effect of design practices on engineering students' learning outcomes. Task-specific problem situations appear to stimulate learners' engagement, in turn improving their learning outcomes. The findings of this study affirmed the important role of design practices in enhancing engineering students' learning outcomes and believed that specific learning tasks could help deconstruct complex knowledge systems and enhance learners' cognitive engagement, to some extent.Second, interactive reflection significantly and positively affected engineering students' learning outcomes. There are two reasons why interactive reflection improves engineering students' learning outcomes: first, interactive reflection offers a crucial way for learners to communicate with the outside world and transform the information they gain into their own knowledge; second, interactive reflection can construct a discourse of mutual understanding and facilitate the application and implementation of technology.Third, the empirical test results show that knowledge integration exerted a positive effect on engineering students' learning outcomes. Knowledge integration demonstrates learners' ability to coordinate and integrate key resources. It also enables the smooth flow of scientific thinking and disciplinary knowledge across boundaries, promotes efficient communication within organizations, and enhances the learning outcomes of engineering students.Fourth, circular iteration was found to positively affect the learning outcomes of engineering students. In student-centered engineering, circular iteration may gradually be marginalized with students' initiative and motivation assuming greater prominence in pedagogy.

4.2 COGNITIVE ENGAGEMENT MEDIATES THE RELATIONSHIP BETWEEN DESIGN-BASED ENGINEERING LEARNING AND LEARNING OUTCOMES

The test of mediating effects revealed that cognitive engagement partially mediated the relationships between design practice, knowledge integration, circular iteration, and engineering students' learning outcomes while fully mediating the link between interactive reflection and learning outcomes. These results were further confirmed by bootstrap resampling, demonstrating that cognitive engagement was an important mediator of the DBEL mechanism and enhanced engineering students' learning outcomes.

4.3 THE MODERATING EFFECTS OF MODES OF ENGAGEMENT ON THE RELATIONSHIP BETWEEN DESIGN-BASED ENGINEERING LEARNING AND COGNITIVE ENGAGEMENT

Modes of engagement were found to significantly moderate the relationship between design-based engineering learning and cognitive engagement. In DBEL, a systematic modes of engagement was more likely to enhance engineering students' learning outcomes than one that is stage-based.

5 CONTRIBUTION TO THE LITERATURE

This study used a large sample to empirically test the effects of four design-based learning characteristics of engineering education on student learning outcomes. Its in-depth investigation of the characteristics of DBEL and their mechanisms of action has addressed several limitations of existing theories. Our holistic framework connects the key aspects of design-based engineering learning to modes of engagement, cognitive engagement, and engineering learning outcomes (see Figure 1). Taking a dynamic perspective, we focused on the characteristics of DBEL in colleges and universities and analyzed its mechanism of effect in more detail. By proposing and rigorously testing a model of DBEL, we have extended the boundaries of research into engineering learning and revealed the systematic correlations among the features of engineering learning under the design paradigm, thereby providing a conceptual and empirical basis for the model. The research establishes an empirical basis for reforming and implementing a design-based engineering learning model in colleges and universities. By examining two different modes of engagement, we show that systematic design-based programs of engineering learning in colleges and universities can improve students' learning outcomes. The study highlights the need for colleges and universities to address the institutional and cultural barriers to providing adequate support for DBEL.

6 LIMITATIONS AND PROSPECTS

This empirical study has several shortcomings. The distribution of the sample may not be fully balanced since, among the 1650 engineering undergraduates who returned valid responses, 46% were from 985 universities, 32.12% were from 211 universities, and 21.88% were from ordinary undergraduate universities.Different universities have different educational resources and students' quality, which may affect the implementation effect of DBEL. Future studies should investigate the effects of institution type on the different dimensions of engineering students' learning performance, as well as any variations that occur according to modes of engagement.

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ACADEMIC PROCRASTINATION IN ENGINEERING STUDENTS

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ABSTRACT

Procrastination is a common phenomenon in students in higher education. To voluntarily delay an intended course of action despite expecting to be worse off for the delay can affect academic performance, cause study delay, but also lead to frustration and stress. This study set out to explore students' beliefs about what causes procrastination, the extent to which online education and the use of digital devices affects their level of procrastination, and their coping mechanisms and ideas about the kind of support a study program can offer to mitigate the effects of procrastination. Focus group interviews were conducted with first-, second- and third year engineering students. Interviews were transcribed and coded to detect general themes in the students' responses. Students hold several beliefs about what causes procrastination, for example situational temptations and distractions, and task aversion. Regarding online education, students tend to procrastinate more. Digital devices are regarded a serious threat for productivity, students use various settings and apps on their phones to battle distraction. To conclude, students cope with procrastination in various ways. Creating study groups, developing fixed working patterns, and breaking down the task at hand are among the most common. Amongst other things, students state that a study program might invest in creating awareness of procrastination, accommodating group work, and creating enough

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separated physical spaces for study and relaxation to mitigate the effects of procrastination. This study will inform the design of a procrastination intervention program.

1 INTRODUCTION

1.1. Background

Procrastination is common phenomenon in students in higher education. The concept can be defined as *"to voluntarily delay an intended course of action despite expecting to be worse off for the delay"* (Steel, 2007, p. 66). It is estimated that 80 – 95 percent of students engage in procrastination in their studies and there is evidence that procrastination is linked with poor performance and reduced well-being (Tice and Baumeister, 1997). Interventions to mitigate the effects of procrastination can have an effect, cognitive behavioural approaches being among the most powerful and lasting with medium to large effect sizes (van Eerde and Klingsieck, 2008). Although there are ways to cope with procrastination, study programs may underestimate the effort it takes for students to do so. What is more, there are indications that online education (Elvers, Polzella, and Graetz, 2003) and the intensified use of digital devices in students (Hidalgo-Fuentes, 2022) has put more strain on students in coping with procrastination. Therefore, continued efforts of study programs to support students in coping with procrastination are needed.

This study is part of the University of Twente Teaching & Learning Fellowship of the first author. The Teaching & Learning Fellows are a selected group of university teachers that spent one day per week on a teaching or learning issue within their study program that needs mitigation. They adopt a scholarly approach to this issue and are supported by a group of educational science experts. Each group of Fellows is expected to work on a certain theme, the theme for the present cohort being "Digitalisation." The main author is university lecturer in the ATLAS program of the University College Twente, a Bachelor of Science program in Technology, Liberal Arts & Science that aims at educating the 'New Engineer' (Goldberg and Sommerville, 2014). The program has embraced the concept of self-directed learning (Gibbons, 2002; Saks and Leijen, 2014), meaning that students attain learning goals mostly in their own way. Students are expected to shape, structure, and plan their own curriculum. Compared to more traditional programs, such educational environment might call upon students' abilities to cope with procrastination more, therefore the need for support might be stronger in ATLAS.

Procrastination is a well-researched topic, with many studies adopting a quantitative, survey-based approach. For this study, a more qualitative approach was adopted to learn about students' own theories about procrastination, the coping strategies they adopt, the role of online education and use of digital devices, and their ideas about the kind of support they would need from their study program. The outcomes of this study and others to come (a study including study advisors and experienced teachers is being planned currently) are a means to identify design principles for a generic mitigation program for all engineering students at the University of Twente which will first be tested and evaluated in the ATLAS program.

1.2 Research questions

The research questions of this study were threefold. The first pertained to students' ideas about what causes one to procrastinate. Any mitigation strategy should be aligned with participants' prior beliefs about the issue at hand. This question was meant to explore those beliefs.
The second research question pertained to digitalisation and its effects on procrastination. This question focused particularly on procrastination in relation to online education and the use of digital devices.
The third question pertained to coping strategies, especially the kind of coping strategies students adopt themselves, but also their ideas about what a study program can do to support students in dealing with procrastination.

2 METHODOLOGY

2.1 Participants

For the first research question, analysis was based upon data collected from six focus groups, two groups of first years (18 – 19 years, seven students, five males), two groups of second years (19 – 20 years, nine students, four males) and two groups of third years and higher (20+ years, nine students, five males). For the two remaining research questions, analysis was based upon one group of first years (4 students, three males), one group of second years (four students, two males) and one group of third years and higher (five students, two males). The groups could contain a minimum of three and a maximum of seven students. There is evidence to suggest (see Steel, 2007, p. 71) that experience affects procrastination, therefore the groups were divided by study year. All participants were randomly selected and approached by email. Ethical approval was requested for this study and granted by the ethics committee in the domain of humanities and social science of the University of Twente.

2.2 Materials

An interview protocol was designed that contained a standard introduction text (including the consent statement), five interview questions and a standard debriefing text. To address the first research question (prior beliefs), participants were asked: *What, do you think, causes one to procrastinate in their studies?* (Question 1 in the interview). For the second research question (digitalisation), the following interview questions were asked: *When the world switched to online education during the recent COVID-19 pandemic, did that affect your procrastination? How?* (Question 3) and *Consider all digital devices you use in your daily life (e.g. your laptop, phone, tablet, smartwatch), do they affect your procrastination in your studies? How? (if negative: how do you cope with that?). Do you use anything on your devices to cope with procrastination in general? Could you elaborate on that?* (Question 4). (Note that this interview question also partly related to the third main research question). For the third question (coping and mitigation), the following questions were asked: *What, in your view, are successful coping mechanisms for academic procrastination?* (Question 2) and *Do you think there is anything a study program* *can do to mitigate procrastination in students?* (Question 5). All interviews were conducted by the main author, the second author assisted in recording each session with a microphone connected to a laptop with Microsoft Teams installed.

2.3 Procedure

For each interview, a separate meeting room was reserved. Before each focus group interview, participants were explained about the aim of the study, the interview procedure, and data treatment. Before the start of the interview, they declared their consent by responding to a consent statement to which they could respond with yes or no. These responses were audio recorded. The interviewer introduced the questions in a standardized way (reading them out loud from the interview protocol) and ensured that each participant could equally contribute to the discussion by, either verbally or non-verbally, inviting them to respond to the question at hand. The interviewer repeated the question when needed and when no new information was brought to the table, the next question was introduced. At the end of each focus group interview students were asked how they experienced the interview and whether they wanted to be informed about the outcome of the study. Participants were explained that they could, at any moment after the interview, approach the researchers with questions, comments, or suggestions.

2.4 Data analysis

All audio files were transcripted using Amberscript (https://www.amberscript.com/en) and edited by the second author to ensure all statements were sufficiently clear to be coded. The protocols were analysed per year group by the main author and checked by the second author. To analyse the data, the researcher first familiarized himself with the transcripts and identified categories (concepts), setting codes for each. Definitions for each code were made to ensure easy classification to each category. For each research question the main categories were identified and these are presented in the results section.

3 RESULTS

3.1 Beliefs about procrastination

The first research question pertained to students' beliefs about the causes of procrastination. For the current analysis, the functional framework of Svartdal and Løkke (2022) was adopted. This framework distinguishes between Antecedent conditions (A), Behavior (B), and Consequences (C). For example, an individual faced with an aversive task (A) might choose to respond with avoidance behavior (B) which leads to stress reduction and alleviated mood (C). This contingency might lead to the avoidance behavior becoming more likely when faced with an aversive task again. For the antecedents, Svartdsal and Løkke distinguish between 1) Situational temptations and distractions, 2) Task aversion and 3) Lack of energy and tiredness. Statements in response to the interview questions fitted well with these categories. Situational temptations and distractions lead to an immediate mood increase compared to when working on a task with a distant desired outcome ("*for me, if I procrastinate, maybe it's because, I don't know, I want to watch a sports event*", "*there's a vast difference in the work environment, because especially in the foyer, you see people, (...) And sometimes you just suddenly like you have a little bit of small talk and suddenly you're in a two hour deep conversation with someone and* *it's suddenly 6:00 pm*”). With respect to Task aversion, certain characteristics of the task could be aversive, thus procrastinating the task would reduce negative feelings (“*usually when I procrastinate, and what I also see around me, is that it's the task that you would normally be doing is something with high mental effort or at least a high mental barrier to start the task*”, “*making the task way larger in your head than that it actually is. And therefore getting paralyzed by only the idea of having to start a task*"). When there is a Lack of energy and tiredness, task aversion increases and procrastinating the task leads to relief (“*because I have any, like, bad feelings inside of me or anything in my head, that's just taking my attention*”, “*I'd say general moods as well. (...) Like I know weeks where I've been like very productive, but I also know weeks where I was constantly procrastinating, couldn't get my focus on things, couldn't like, just the threshold to start working felt so big*”). Svartdal and Løkke also identify factors that interact with the antecendents, like temporal distance (“*you need to do something within three weeks, but then something pops up that needs to be done in one week. Then that like only time wise that has priority*”) and certain individual difference variables (e.g. a student mentioning not having the proper personal “*characteristics*”).

3.2 Procrastination and digitalisation

The second research question related to procrastination in relation to digitalisation, especially online learning, and the use of digital devices. Regarding online learning, not a clear picture emerged from the data. On the one hand, students stated that they would procrastinate more because of lack of consequences for not producing work, low expectations on the part of the study program (the first-year participants were still in high school when they switched to online education), distractions at home and increased flexibility (e.g. the possibility to watch online lectures in their own time). On the other hand, students stated that lack of certain distractions (e.g. social ones) were helpful in getting work done. The second years found it hard to say anything about online education and procrastination, because when the COVID-19 pandemic happened, they also switched from high school to university.

Regarding using digital devices, the distractive and addictive nature (difficult to escape “*from the rabbit hole*”) of media content was mentioned (Instagram, TikTok, Facebook, YouTube, Netflix). Especially the fact that phones can be used for work and leisure apparently poses a serious challenge *(“it's just, you can do anything on it”*). Loss of focus due to engaging with media content (“*and then someone else wants something from you that has nothing to do with what you're doing at the moment. And then you're already in a completely different mindset thinking about something else”*) and easy accessibility were also mentioned.

3.3. Coping with and mitigating procrastination

The third research question concerned students’ coping mechanisms regarding procrastination. In general, social accountability (e.g. arranging a study group), fixed working patterns, breaking down the task at hand, identifying attractive features in the task, building up to the point of actual engagement (e.g. doing small tasks to make the transition to doing a task one is procrastinating on), manage distractions (e.g. giving one’s phone to someone else for a while) and self-nudging (e.g. having a certain background on one’s screen, organizing one’s desk, or changing one’s working environment) were most commonly mentioned. To a lesser extent, goal setting, planning breaks (as a rewarding mechanism), gamifying (e.g. counting how many pages one can study in a certain time and then try to beat that time) and time blocking (taking a certain amount of time to do something) were mentioned. With regard to the use of digital devices, students mentioned applying devise configurations (e.g. deleting distracting apps, using apps like Google Calendar, TimeTree, OneSec, Notion, set focus modes, use black and white settings, disabling notifications, set do- not-disturb settings, muting group chats, turning sound off, and make to-do-lists with check boxes that include smileys and satisfying visuals). To a lesser extent, students mentioned using separate phones (for work and pleasure) or deliberately do certain tasks on paper that they could also do on their phones.

Reflecting on what a study program could do to mitigate procrastination students mentioned creating awareness about the issue, fostering social accountability (e.g. by accommodating group work and have mentor meetings), proper planning (of deadlines), accommodate choice (on learning content, - approach and assessment of learning), promoting well-being, offering relevant learning content, designing a functional physical study environment (with ample and separate spaces for study and leisure) and proper planning of study breaks.
No systematic differences related to age category in responses to the interview questions were detected, although the third-year groups tended to give more elaborate answers, indicating a higher level of experience with procrastination.

4 SUMMARY AND ACKNOWLEDGMENTS

In summary, this study identified students' beliefs about what causes procrastination, the extent to which online education and the use of digital devices affects their level of procrastination, and their coping mechanism and ideas about the kind of support a study program can offer to mitigate the effects of procrastination. The insights propose several ideas for an intervention strategy that could contain personal (e.g. creating awareness, individual and group strategies) and environmental aspects (e.g. proper planning and creating optimal physical learning spaces).
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STUDENTS' EXPERIENCE OF FEEDBACK PRACTICES AND RECOMMENDATIONS FOR IMPROVEMENT

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ABSTRACT

There have been numerous research studies and recommendations as to what feedback should look like to improve student learning and the learning experience. These recommendations include being timely, fed forward, provided using different modes and sources and to support students to know how to best use the feedback they are given.
The Faculty of Engineering and IT (FEIT) at The University of Technology Sydney (UTS) is currently focusing on improving the quality, effectiveness and delivery of feedback provided to their students on their learning and demonstrated achievement in a variety of settings.

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This paper reports the first stage of this project where students were asked about their previous experience of receiving feedback, how they are able to use it and their preference as to the type and timing of the feedback they prefer.
Students reported feedback was often was non-existent, extremely limited, non-specific, or too late to be useful. They found feedback was most useful when it was specific, could be used for improvement and was not just focused on correction.

1 INTRODUCTION

Not surprisingly, good feedback has a positive impact on learning (Hattie and Timperley 2007, 81–112). While there is considerable literature reporting how to make feedback effective, student surveys often report that the feedback they receive as being unsatisfactory and or of little use (Carroll 2014). In fact, looking at the average results for the student satisfaction surveys (SFS) for UTS in the spring semester 2022, 10% of students disagreed and 14% of students chose neutral in response to the statement:

Overall, I received constructive feedback throughout this subject.

While one could interpret this as being a good result, in that, only 10% of students disagreed with the statement (although 14% were neutral) it could be argued that this is a simplistic view.
Firstly, only 497 of the 1168 subjects taught in the University that semester (43%) included a question about feedback in their SFS and hence contributed to this result.
Secondly, the question is rather simplistic and as described by Dawson et al (2019, 25-36) is based on an outdated understanding of feedback.
Similar to questions in other student surveys that tend to ask if students are satisfied with the amount and quality of feedback they receive (Winstone and Pitt 2017) the question does not ask and hence indicate whether the feedback was effective in helping students learn and improve. Work by Sadler, Carless and Molly and Boud suggests feedback to be a process that leads to learning (Dawson et al 2019, 25-36; Sadler 2010b, 535–550; Carless et al. 2011, 395–407; Molloy and Boud 2013, 11–33).
Hence, to investigate whether our feedback practices are effective we first had to decide on the characteristics of feedback that promote learning and improvement.

2 METHODOLOGY

A review of the research on feedback revealed an Australian Office of Learning and Teaching (OLT) project conducted by Deakin, Monash, and Melbourne universities (OLT Project, 2018). The project’ s aim was to “improve learner, educator and institutional approaches to student feedback”. It considered feedback to be “a process through which learners make sense of information from various sources and use it to enhance their work or learning strategies” (OLT Project, 2018).
The project team found that to facilitate successful assessment feedback one needs to consider the capacity, design and culture for feedback (OLT Project, 2018).
More specifically, the Centre for Research and Assessment in Digital Learning (CRADLE) at Deakin University Australia, recommended the following nine strategies for feedback to make a difference in student’s learning (CRADLE 2023):

1. Design follow-on tasks so that learners can apply the information received
2. Move feedback earlier in the subject so learners have time to act
3. Have learners judge their own work against criteria before they submit it
4. Support learners to know what feedback is and how they can make it work for themselves
5. Focus on comments for improvement rather than corrections
6. Initiate peer feedback activities that focus on producing improved work
7. Invest time in developing your teaching/ marking team
8. Personalise feedback comments to individual learners
9. Consider different modes of providing feedback comments

A research survey based on the OLT Project and the nine recommendations by CRADLE was produced to evaluate the experience of FEIT students with the Faculty's feedback processes. The survey was refined through pilot testing to improve validity and remove ambiguity. The survey was made available to students in April and May 2023 after obtaining ethics approval.
While the survey is still open, monitoring of the results suggest that they are sufficiently stable (have approached saturation in that additional responses are not indicating any new variations) to inform the preliminary findings presented in this paper.
The analysis preliminary findings and recommendations from this survey were subsequently released and discussed with staff in the Faculty. They have also been used to develop workshops for all academic staff, aimed at improving the Faculty's feedback processes. These are planned for late July and early August 2023.

2.1 Method

The anonymous survey consisted of 15 questions.
The first four questions (one Likert scale, three open ended) gathered data about students' beliefs about the feedback they received. These included questions that asked students how satisfied they were with the feedback they received over the last 12 months, the reasons for their answer and describing what feedback they regarded as helping them the most and the least. The three open ended questions were analysed using a thematic analysis.
The next three questions were multidimensional in that they used a Likert scale to ask students how frequently 12 statements (four statements in each question, grouped to reflect three themes) occurred in their subjects. The statements were derived from the effective feedback strategies recommended by CRADLE presented earlier in this paper. The Likert scale used was:

Never	This happens in less than 25% of subjects	This happens in 25% to less than 50% of subjects	This happens in 50% to less than 75% of subjects	This happens in 75% or more of subjects

The final seven questions gathered demographic data. They were included to analyse the results for different groups of students. The questions asked about gender, age, year of study, current weighted average mark (WAM), whether students were domestic or international and which Engineering or IT degree they were studying.

The analysis findings and recommendations from this survey were released and subsequently discussed with Faculty staff who provided feedback on the findings and recommendations.

3 PRELIMINARY RESULTS

Overall, about half (47%) of the 178 student respondents were at least somewhat satisfied with the feedback they received on their learning in FEIT subjects in the last 12 months.

Table 1: Results from the question: Think back to the feedback you received on your learning in FEIT subjects in the last 12 months. Overall, how satisfied are you with this feedback?

	Percentage
Extremely dissatisfied	4%
Somewhat dissatisfied	24%
Neither satisfied nor dissatisfied	26%
Somewhat satisfied	37%
Extremely satisfied	10%

When students described the reasons for their dissatisfaction with the feedback they received or the characteristics of feedback that help them the least, the dominant themes (from the thematic analysis) were that the feedback was non-existent, extremely limited, non-specific, or too late to be useful as indicated by the sample of responses presented below.[2]

3.1 Limited or non-existent

> *we did not receive any feedback on our assessment items, just the mark. This meant that we did not get any indication of why we received that mark and how to improve. . (Male, Second Year Undergraduate, WAM ≥ 85)*

> *there was little to no written feedback, I was only provided my marks according to a rubric – (not usually obvious where I went wrong). (Female, Undergraduate, Third Year, 75 ≤ WAM < 85)*

3.2 Non-Specific

> *the marking rubrics are often poorly defined, having multiple overlapping criteria or are unclear, and the associated comments typically do not explain much of the reasoning behind the grade, if there is even a comment at all. (Male, Undergraduate, Third year, WAM ≥ 85)*

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[2] *Note: the grammar and spelling in some of the presented student responses has been corrected, to both protect any contributing student who may read their comments in this paper from embarrassment or discomfort and to improve readability.*

Often the feedback is short and non-constructive. I have often received feedback like "yes", "good", "interesting", "no", "more", and "elaborate". Non-specific feedback is not useful and doesn't help me grow. It especially becomes confusing when you are given a low mark but the feedback is not proportionate. (Gender identity not shared, Undergraduate, Third year, WAM ≥ 85)
Feedback that is not helpful are general comments such as "Well done but this section could be improved." This comment does not say what specifically needs to be done to improve, so is not actionable. (Male, Undergraduate, Second year, WAM ≥ 85)

The markers only leave positive and encouraging comments on my work, but I see that marks have been taken off. They follow the rubric and highlight the score I received for each question. However, when I lose marks on the rubric, there is no indication of how I can improve, or why I lost marks. (Female, Undergraduate, Fourth year, 75 ≤ WAM < 85)

Often the feedback is extremely limited or generic (sometimes classmates compare the feedback comments for an assignment and realise we've all received the same comment!) - you're left not really understanding where you went wrong (for example, the comment won't point to specific sections to help show you where you made the mistakes), or thinking that you DID do whatever the comment says you didn't do correctly! It means that you haven't really learned what mistakes you made, let alone how to improve upon them the next time. The flipside is that feedback very rarely points to what you did really well with either, so even if you get a good mark, you're not entirely sure why, or how you could continue to improve. This is, of course, assuming that you get feedback at all. (Female, Undergraduate, Third year, WAM ≥ 85)

3.3 Too Late

Most feedback takes too long to get to be useful or is just very minimal. (Male, Undergraduate, Second year, 75 ≤ WAM < 85)

Sometimes feedback, if provided, is released very close to the due date of the next assignment, so it's very difficult to make improvements for the upcoming assignment. (Male, Undergraduate, Fourth year, WAM ≥ 85)

3.4 Good Feedback

Unsurprisingly when students were asked to describe the characteristics of the feedback that helped them the most, the most dominant themes were feedback that was specific, could be used for improvement and was not just focused on correction:

whenever marks are deducted good detailed feedback on improvement is provided and not just why marks were deducted. (Male, Undergraduate, Fourth year, WAM ≥ 85)

Feedback that describes exactly in detail what I did wrong/right and what I can improve /change to make my work better. (No demographic details provided)

Well-structured and easy to read, it got to the point and gave things to improve. (Male, Undergraduate, Third year, 75 ≤ WAM < 85)

Actionable - the feedback helped guide you to action you could take to improve (Male, Undergraduate, Third year, 75 ≤ WAM < 85)

Feedback that thoroughly listed what I had done well, what I could improve to receive a better grade, and what I could do in general to improve. (Female, Undergraduate, Third year, 75 ≤ WAM < 85)

Another common theme of good feedback was feedback that was provided in person and through conversations with their tutors and academic staff.

In-person feedback about what things, I can improve on and what things I should work towards. (Male, Undergraduate, Second year, 65 ≤ WAM < 75)

The feedback that I enjoy the most would be 1 on 1 talks with the tutor/teacher where they get to know me, and why I did what I did. This feels more engaging when talking to a human in person. (Male, Undergraduate, First year, I don't yet have a WAM)

Getting in-person feedback whilst being able to view the marked assessment is cool. (Male, Undergraduate, First year, I don't yet have a WAM)

When asked to rate against a five-point Likert scale how frequently a series of statements about feedback occurred in their FEIT subjects in the last 12 months, at least 60% (59% in the case of statement five) of the student respondents reported the following statements occurred in less than 50% of subjects:

1. Lecturers explain how they will give me feedback, and how to use it to improve my future work and learning.
2. Feedback activities are used early in the semester so I can use the feedback to improve my work within the semester.
3. The feedback comments I receive are focused on improving my future work not just correction of my submission.
4. The feedback comments I receive about my work are personalised and at least some are specific to my work.
5. I am asked to self-assess my work against the assessment criteria before submission, to develop my ability to judge my progress.
6. I am asked to evaluate the work of my peers (other students) to develop my judgement and benefit from peer feedback about my work.

4 DISCUSSION AND RECOMMENDATIONS

As stated earlier, the survey is still open and results have yet to be examined for different demographic groups to determine more nuanced findings. However, the preliminary findings show there are several feedback strategies for improvement recommended by CRADLE in which we are underperforming.

As a first step to improving the Faculty's feedback processes we will be holding a series of all staff workshops that will focus on facilitating the immediate implementation of the following to improve feedback effectiveness.

1. Improving learning and assessment activity scaffolding through lecturers and tutors specifically explaining how they will provide feedback, and how it is recommended to be used for learning and improvement.
2. Personalise feedback comments to individuals. Students are more motivated to engage with feedback and improve when they are treated as individuals and feedback is personalised to their own work (Dawson et al. 2019). The minimum improvement being to use a student's name at the beginning of their feedback.
3. Ensure that feedback comments are specific and focus on improvement rather than simply correction and/or justifying the awarded mark including:
    i. what was good about the submission and why
    ii. what needed to be demonstrated to achieve a higher grade
    iii. how the student could use the feedback in their next task
    iv. what the student should focus on in their skill development and future learning
4. Ask students to self assess their work against the assessment criteria before submission. This is easily achieved by having students indicate in an assessment rubric included with their submission, the level of achievement they believe they have demonstrated against each criterion.
5. Design subject learning and assessment activities to enable students to learn and check their progress/understanding/judgement from feedback that can be utilised later in the subject.
6. Require all subjects to include an improved question about feedback in their student surveys. For example,

Overall, I received specific feedback in this subject that helped me learn and/or will help in my future learning.

These recommendations have been released and discussed with Faculty staff to seek their feedback.
It was discussed with staff how improving scaffolding, ensuring feedback comments are specific and actionable and asking students to assess their own work (recommendations 1, 3 and 4) and modifying learning and assessment activities to include early feedback for improvement (recommendation 5), should contribute to both improving academic achievement and feedback literacy.
Feedback literacy is the understanding, capacity and disposition needed to make sense of feedback and use it for improvement including changing behaviour, response, enhance/improve work or learning strategies. In explaining and scaffolding feedback literacy to both staff and students Carless and Boud's (2018, 1315-1325) framework depicting four inter-related features: appreciating feedback; making judgments; managing affect; and taking action will be used.
Academics reported that students often expect mark inducements to take action and/or to engage and comply with processes. Several academics felt that without such inducements many students would not engage and/or participate in the recommended feedback processes. Other issues discussed include the importance of scaffolding to students that mark inducements often result in awarding marks for activities not listed as a learning outcome and can facilitate the accumulation of marks for early work that is below the level of a subject' s satisfactory achievement (Sadler, 2010a, 727-743).

5 CONCLUSION

Feedback provided to students often focuses on correction and justifying the awarded mark. To make feedback more effective it needs to be forward looking and focus on helping students learn and improve. In this paper we have evaluated students' experience of feedback processes within an Engineering Faculty and recommended processes to improve its effectiveness to facilitate learning and improvement.

Students reported currently feedback was often was non-existent, extremely limited, non-specific, or too late to be useful. They found feedback was most useful when it was specific, could be used for improvement, was not just focused on correction, and delivered in person.

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Can Students' Self-Efficacy Beliefs Explain Academic Motivation and Career Intentions?

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ABSTRACT

In our technologized and increasingly complex world, jobs in STEM make a crucial contribution to innovation and sustainability. However, there are still many vacancies in this field. To tackle the shortage of professionals, it is even more important to successfully prepare qualified young people for engineering careers and foster competences that promote innovative and creative solutions. In addition to cognitive abilities, research has shown how self-efficacy, which describes confidence in one's own abilities to successfully overcome obstacles, can influence students' motivation, interest and therefore academic and vocational training success. Studies show that people with a strong belief in their own competence have greater persistence in completing and problem-solving tasks. Hence, this paper discusses how the students' own perception of self-efficacy can influence their interest in the subject, academic retention, and subsequent career intentions and success. To gain further empirical insights, data from the mixed-methods study "digiMINT" will be collected using narrative interviews with female pupils, STEM students and employees, as well as industry representatives. The aim is to understand conditions of engineering education and jobs, and additionally the perception of self-efficacy as a predictive

factor of career intentions. Furthermore, it will be evaluated how self-efficacy can be cultivated as a valuable skill in engineering education and teaching additionally to cognitive skills. In long term, promoting a positive experience for students' own self-efficacy could support a sustainable integration into the labor market and equip future engineers with an interdisciplinary which is particularly relevant for complex tasks in an increasingly complex world.

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1 INTRODUCTION

1.1 Background to the Research

A lack of mechanical and plant engineers as well as a high female dropout rate is a concern in Germany. The current challenges of our complex and sustainability-oriented world, such as demographic change, digital transformation or mobility turnaround in the face of the climate crisis, intensify the ongoing shortage of skilled workers. Particularly in the field of mechanical and plant engineering, which is a key industry sector for Germany, enormous disruptions due to advancing digitalisation processes can be observed and are still to be expected (Kagermann et al. 2013). In addition, there is a high dropout rate in STEM fields, where many potential STEM graduates get lost (Chen 2015). Digitalisation is accelerating in many areas of society, including industry, work, education and social life. This makes STEM, and especially key STEM occupations, increasingly important. (cf. Frielingsdorf 2019) Therefore, the subjects of electrical engineering, information technology, computer science and mechanical engineering as well as process engineering are of particular interest.

In addition, women are still under-represented in STEM subjects, particularly in engineering and computing, which are central to mechanical and plant engineering, although the number of female students and graduates is increasing. While the proportion of women in the first semester of these subjects increased from 13.39 per cent in winter semester 1998/99 to 21.62 percent in winter semester 2019/20 (Destatis 2021a), the proportion of women graduating in these subjects increased as well from 8.8 percent in 1999 to 19.73 percent in 2019. Only 18.5 percent of female graduates were found in core production and manufacturing jobs 12-18 months after graduating. (Destatis 2021b) Although there is an increasing share of women, not many of them are choosing careers in this field (Thomsen, Schasse, and Gulden 2020, 20). For that matter women still do not participate to the same extent as men, who dominate this field (Bandura et al. 2001). Hence, there are still wide gender disparities in career intentions and pursuits (Smith and Fouad 1999).

An explicit analysis of how women choose these STEM subjects and careers is particularly worthwhile valuable in the context to potentially disruptive trends and changes affecting the core STEM sector of mechanical and plant engineering. Since the under-representation of women engineers in mechanical and plant engineering is thought to have both cultural and structural causes (Jeanrenaud 2020, 22–30), the aim is to gain a better understanding of the factors that influence individual career and life trajectories and how they relate to social and organisational contexts. Research will also focus on how to attract and retain women in STEM careers in a sustainable way.

1.2 Theoretical Framework / State of Research

Most career choice theories explain the necessary steps involved in choosing and implementing a career. Individuals must be aware of their skills, interests, individual characteristics and needs. However, personal self-efficacy and expected outcomes are mostly neglected. Despite existing talents, a person may doubt their own talent and suitability for the job. Consequently, their self-efficacy and individual outcome expectations would be low. The social-cognitive career model (Lent, Brown, & Hackett, 1994), based on Bandura's (1997) social-cognitive theory, explicitly includes these factors.

Hence, a very important dimension in the causal structure of this theory is the central role of self-efficacy. Self-Efficacy beliefs do not only affect adaptation and change themselves, but also by influencing other determinants. As a theoretical framework it explains career intentions through the influence of interests, outcome expectations and their evaluation, self-efficacy expectations, and contextual factors. (Bandura et al. 2001) Following Bandura (1977) we differentiate between self-efficacy expectations and outcome expectations. Self-efficacy is described as confidence in one's own ability to overcome obstacles and perform certain tasks successfully in the future. Outcome expectations are personal beliefs about the imagined consequences of certain actions. Self-efficacy can influence expected outcomes, but not the other way round. (Bandura and National Inst. of Mental Health 1986) Both outcome expectancies and self-efficacy beliefs are assumed to predict interest in a specific area. (Smith and Fouad 1999) Self-efficacy beliefs were found to contribute even more to career preferences than expected outcomes. This was particularly the case for women. They based their career preferences more on their perceived efficacy than on the attractiveness of the potential benefits of the occupation. (Bandura et al. 2001) But even with comparable prerequisites and identical professional self-efficacy as men, women still tend to expect lower outcomes. They expect to face greater difficulties and therefore are satisfied with less. (Abele-Brehm and Stief 2004)

In addition, a significant correlation has been observed between academic self-efficacy and persistence in higher education. (Gore 2006) Consequently self-efficacy beliefs play a major role for career development and aspirations (Abele-Brehm and Stief 2004). Self-efficacy beliefs correlate with career intentions, such as choice of occupation and career field, but also with success in the career field. However, there was no correlation found between gender and career intentions, when controlling for self-efficacy. Moreover, self-efficacy is correlated to career intentions when controlling for objective performance. (Epstein and Fischer 2017) Additionally, Self-efficacy beliefs, when controlling for differences in ability, prior educational attainment and aptitude, and career interests, predict career choice and mastery of the educational requirements for those careers. (Lent, Brown, and Hackett 1994)

If self-efficacy is high, one sees oneself as capable to master educational requirements and job-related skills, and expects positive results. As a result, the range of career options becomes wider. (Bandura et al. 2001) This leads to the development of interests relevant to that particular choice of work life, better preparation for the career path, and persistence in pursuing a career in that field. So self-efficacy mediates between skills and performance. Moreover, interests, together with self-efficacy and outcome expectancies, predict aspirations. (Smith and Fouad 1999)

Lower self-efficacy beliefs and consequently lower interest in maths and science could therefore explain the under-representation of women in technical professions such as mechanical and plant engineering to a certain extend. Thus, direct interventions targeting one's self perceived attributions and self-efficacy ought to have a significant impact on individual aspirations and career choice. Within the context of mechanical and plant engineering, self-efficacy based interventions could therefore help to promote interest in that specific area. (Smith and Fouad 1999) However, it is assumed that self-efficacy is by no means the only factor influencing the career intentions of graduates but can serve as a valuable skill to be taught and trained.

Though the research project is still in the process of conducting the survey and interviews. Consequently, the first empirical results are not yet available. Therefore, this paper presents the background of the research project, the methodological approach, and the theoretical framework for exploring self-efficacy in engineering education and professional development.

1.3 Research objective

The intention of this paper is to emphasize the perception of students' self-efficacy as a predictive factor and its relevance for academic capabilities and expected outcomes, such as career intentions and trajectories. The evaluation of self-efficacy expectations in the survey want provide context-specific insights into the factors that influence self-efficacy in this field. (Bandura and National Inst of Mental Health 1986).

In-depth questions inspired by the BSW scale (Knispel et al. 2021), which is a validated instrument for use with students and employees that measures expectations of vocational self-efficacy in an economic way. Conceptually, this scale reflects motivational and skill-related aspects of occupational self-efficacy. (ibid.)

The project aims to investigate the perceptions of self-efficacy among students in mechanical and plant engineering. Specifically, it will focus on their beliefs about their ability to meet educational requirements, possess relevant skills, and maintain interest in the field. The project will also explore how students' confidence in their abilities influences their study-related intentions and expected outcomes. Additionally, the project will examine the motivational and competence-related aspects of vocational self-efficacy.

It is particularly interesting to explore the significance of self-efficacy perception for women engineers in decision-making processes related to their study course, career intentions, and persistence in pursuing a career in the field. It seeks to understand how self-efficacy influences choices of occupation and career field, beyond objective performance measures. Additionally, the study will investigate the impact of learning experiences and contextual factors on self-efficacy, as well as potential indirect effects of self-efficacy on career behaviour.

1.4 Research Question

The research seeks to gain a comprehensive understanding of the factors that contribute to self-efficacy of female students and professionals in mechanical and plant engineering. The focus lays on exploring the perception and relevance of self-efficacy for female students in this field, as well as their experiences in learning, working, social, and motivational contexts. The emphasis will lay on identifying the various factors, such as social, cultural, learning, and working contexts, support systems, and resources, that promote or hinder the development of self-efficacy in female students and professionals in mechanical and plant engineering. This includes exploring the role of stereotypes, gender biases, and societal expectations in shaping self-efficacy beliefs.

Therefore, the following research questions will be addressed:

1.) *What influencing factors (e.g. social, cultural, learning or working contexts, support systems or resources) and how do they promote or hinder the development of self-efficacy in female students and professionals in mechanical and plant engineering?*

2.) What are the potential barriers and challenges faced by female students in mechanical and plant engineering in terms of their learning, working, social, and motivational contexts, and how can these be addressed to promote self-efficacy?

3.) How does the perception of self-efficacy among female students in mechanical and plant engineering influence their motivation, career aspirations and persistence in the field?

In addition, the focus will be on how these findings can be implemented in engineering education and teaching as well as in business contexts. There is evidence from empiric research that self-efficacy develops with experience on task and can be influenced by positive feedback and causal attributions. In particular, feedback and attributions about how well one performs is suspected to directly affect self-efficacy, and consequently, aspirations and possible outcome expectations. Thus, self-efficacy and aspirations can change over time any may be subject to intervention. This is particularly in line with the predictions of social cognitive theory of Bandura which suggest that individuals are motivated to perform at higher levels as long as they feel capable of achieving their set goal. This is especially decisive who attribute their performance to internally controlled factors, who sees the positive outcomes as a result from individual's own ability. As shown, self-efficacy is positively correlated with individual aspirations, hence changes in perceived self-efficacy lead to changes in outcome expectations. The art of feedback can have a direct impact on how high persons set their individual goals. (Tolli and Schmidt 2008)

This suggests the importance to build students' self-efficacy as a valuable skill additionally to cognitive skills. Regular, constructive feedback could be one way in engineering education and teaching. Interventions that focus on feedback, attributions and self-efficacy can have a valuable practical impact (Tolli and Schmidt 2008) to reduce drop-outs and enable a smooth transition from the study to work life for graduates. The upcoming survey will provide more insight to how individuals experience their study and the teaching regarding her own perception of self-efficacy, how they achieve in the subject as well as how they assess their own performance during the study. It is therefore up to research to what extend feedback could be more integrated in engineering education and teaching in order to positively influence students' self-efficacy.

2 METHODOLOGY

2.1 Empirical Concept and Research Design

This paper is based on our ongoing project, funded by the German Federal Ministry of Education and Research (BMBF) (01FP22M01). It focuses on the under-representation of women in STEM, particularly in mechanical and plant engineering, in order to address the shortage of skilled workers in this sector, which plays a vital role for the German industry. The aim is to analyse the factors that contribute to the successful recruitment and retention of women in mechanical and plant engineering. The main objective is to investigate the decision-making processes that encourage or discourage women engineers from taking up certain types of jobs in the engineering sector. The methodological approach focuses on which socio-cognitive, cultural and contextual factors are most likely to explain individual career and life trajectories of women engineers in this field.

The study began in October 2022 with an extensive literature review. This will be supplemented by a mixed-method-design, combining qualitative and quantitative empirical methods, which is particularly suited exploring these issues in depth.

2.2 Data Assessment and Analysis

Five cohorts of female students in different semesters, graduates and young professionals were interviewed as well as people in management positions at companies were surveyed with a questionnaire. Both will be recruited via snowball system and contact persons of the companies of various actors in the field (e.g. associations, universities, national and local women engineers' networks).

As the research focuses on cultural and structural reasons, qualitative, problem-focused interviews will be used to explore how these affect individual professional and career paths (Dröge 2020) with female students and engineers. The survey is based on telephone and/or video interviews with these five cohorts of around ten people each who are studying or have graduated in a STEM subject relevant to mechanical and plant engineering, with a significantly low proportion of women even among STEM fields. The research thereafter will survey and retrospectively analyse the choices of female STEM students and reflect on the active orientation of female pupils in their choice of study. Moreover, we want to gain more detailed insight into the factors that influence the course of STEM studies and the transition to work. Self-efficacy is a crucial aspect and should always be addressed and evaluated as a cross-cutting issue. The aim is to understand the influence of learning experiences and contextual variables on self-efficacy, as well as the possible indirect effects of self-efficacy on career behaviour of women engineers. It will be focused to what extent self-efficacy perception is a predictive factor to improve women' participation in STEM, thus self-efficacy is correlated to interest and development of skills relevant of that field, as well as career intentions and persistence, as already mentioned. This will provide valuable insights into the role of self-efficacy in shaping the career trajectories of STEM graduates.

Furthermore, the questionnaires also aim to include the business perspective by gathering insights from individuals in management positions. This helps to understand how organizations and employers can support and enhance self-efficacy, career development, and the successful transition of STEM graduates into the workforce as well as their retention. This includes identifying the specific technical and non-technical skills that are valued by employers, and understanding the organizational policies, frameworks and practices that support the career development, job satisfaction, and engagement regarding self-efficacy. Therefore, a standardised online questionnaire for management positions within the fields of Mechanical and Plant Engineering is planned to gather further information. We are expecting to receive around 380 responses in order to get a representative picture of the situation in mechanical and plant engineering for Germany. The aim is to gather more insight to their perspective and to better understand the factors that contribute to fostering self-efficacy in the context of mechanical and plant engineering.

The total of approximately 50 interviews will then be transcribed and analysed using qualitative content analysis. (QIA) (cf. Schreier et al. 2019; Schreier 2014) according to Philipp Mayring (cf. 2016) and Udo Kuckartz (cf. 2016). The analysis software MAXQDA[1] is used for this purpose (cf. Steinke 2007). The open source software Limesurvey[2] is used for the online survey of companies in the mechanical and plant engineering sector.

[1] www.maxqda.de

[2] https://community.limesurvey.org/

3 RESULTS

Detailed analysis of the data collected through qualitative interviews and statistical analysis of responses to the online questionnaire will be conducted and collated once the survey is completed. Final results are expected by the end of 2025, but first first interim results arising from the interviews shall be presented beforehand. The findings ought to provide insights how the perception of self-efficacy among female students in mechanical and plant engineering influences their motivation, career aspirations, and persistence in the field. This includes exploring the relationship between self-efficacy and career decision-making, goal-setting, and career advancement. The research will shed light on how social and cultural factors influence the development of self-efficacy in female students in mechanical and plant engineering. This includes exploring the role of stereotypes, gender biases, and societal expectations in shaping self-efficacy beliefs. First insights into the learning and working environments that promote or hinder the development of self-efficacy in female students will be provided. This includes examining e.g. the role of supportive learning environments, access to resources or opportunities for hands-on experiences in fostering self-efficacy.

Overall, we expect the findings will uncover the challenges and opportunities faced by graduates during their study and transition from academia to workforce. Understanding these challenges will help in developing strategies to address them and promote self-efficacy. Furthermore, the anticipated findings will provide valuable information on the employer perspective, helping to bridge the gap between the expectations of employers and the experiences of STEM professionals. The findings and insights from the analysis can help educational institutions and policymakers align their curriculum and training programs. Furthermore, the results can guide employers in creating a supportive and engaging work environment for STEM professionals that enhance the alignment between the needs of employers and the experiences of STEM graduates, ultimately contributing to the successful integration of STEM talent into the workforce. Appropriate measures, actions to be taken and, where necessary, further research will be identified. In this way, a cultural change should be initiated and promoted in the long term to attract and retain more female STEM graduates in industrial companies, considering the diversity of women's specific life situations. We aim to develop empirically based recommendations for industry, academia and politics to address the underrepresentation of women in STEM based on findings from the project itself. (cf. Jeanrenaud 2020)

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‘THERE’S A MACHINE ON THE TEAM’: EMPLOYERS’ PERSPECTIVES ON GRADUATE EMPLOYABILITY IN DIGITISED WORKPLACES

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ABSTRACT

The implementation of interconnected digital and cyber-physical technologies across engineering fields is changing the nature of professional work. These new forms of work present both technical and social challenges; it is therefore timely to consider the implications of the digital transformation of work for engineering education. In this study the focus is on the technical and social skills that employers have identified as desirable for productive work practices in digital/cyber-physical environments. The research question guiding the study is: What technical and social skills do employers in digitised/cyber-physical workplaces value in engineering graduates? The study drew on Legitimation Code Theory’s Specialization dimension to reveal the

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underpinning principles of how technical and social skills are integrated in digital environments. Structured interviews with employers were analysed to categorise the technical and social skills that were highly regarded in environments that had implemented digital and related technologies. The study identified three levels of socio-technical integration valued by employers, namely: 1) enthusiasm for, and appreciation of, the role of digital and related technologies in addressing engineering and societal challenges; 2) teamwork and/or client support in digitised environments; and 3) interdisciplinary and transdisciplinary collaboration for digital and related technological innovation. The study identified an emerging shift from a skills discourse that assumes a separation between technical and social skills towards one that captures the dynamics of socio-technical integration in digitised and related technological practice.

1 INTRODUCTION

1.1 Background, research problem and focus

Many workplaces are undergoing forms of transformation that can largely be attributed to the digitisation of work (Jensen, 2018). Implementing digital and related technologies in engineering work presents both technological and social challenges, described as the ‘socio-technical evolution of the human role in production systems’ (Frank et al. 2019). Thus, as well as transforming production and services through digitisation, employers face the challenges of recruiting, training, and supporting staff at both operational and managerial levels. The digital transformation of work consequently poses challenges for professional practice and engineering education. The problem that this study has identified is a mismatch between the technical and social skills required in digitised workplaces and the forms of knowledge and skills acquired in engineering education. The impact of advanced technologies on professional education is underrepresented in the literature, and it is this issue that this study addresses. The guiding research question for the study is: What technical and social skills do employers in digitised/cyber-physical workplaces value in engineering graduates? Although changes in machinery and technology are obvious, and have a direct impact on practice, the more challenging issue is to adapt ‘the human side of the transformation to the new work settings’ (Rangraz and Pareto 2020). Because digital technologies are often disruptive in nature, when they are put into practice, they necessitate the acquisition of new skills sets and mind sets. It is generally acknowledged in innovation studies that in order for technological innovation to be adopted, social innovation must first occur (Charalambous et al. 2017) yet ‘worker-level factors explicitly aligned with emerging cyber-physical systems receive little attention’ (Blayone and Van Oostveen 2020). In order to address this gap, it was necessary to draw on theoretical tools that could identify the principles underpinning the emergence of new engineering technical and social skills in digitised work environments and to consider their implications for engineering education.

1.2 Theoretical framing

The study required an analysis of changes in practices brought about through advanced technologies. The Specialization dimension of Legitimation Code Theory (Maton 2013) was chosen because it explains the nature of specialised practices. The principles underpinning practices were revealed using specialization tools to analyse varieties of technical and social skills. All engineering practices involve technical and social skills. Practices in workplaces will therefore always include technical and social dimensions because the accomplishment of engineering work involves tools and people.

Table 1. The Specialization Dimension

Technical skills		Social skills	
Stronger ↕ Weaker	Technical skills are highly important for practice.	Stronger ↕ Weaker	Social dispositions are highly important for practice.
	Technical skills are less important for practice.		Social dispositions are less important for practice.

Source: Adapted from Maton 2013.

Table 1 explains that technical and social skills could be stronger or weaker in different work practices. There are likely to be cases in which specialised engineering knowledge and technical skills are emphasised, as well as cases in which professional dispositions and social skills are more important. There are also likely to be work practices in which both technical and social skills are equally important. The relative strengths of the technical and social dimensions can change over time, particularly when new technologies are introduced into workplaces. Applying the specialization tools in this study revealed how employers conceptualised the appointment of new graduates in terms of their technical skills (e.g., qualifications in renewable energy technologies), and in terms of social skills in the work environment (e.g., a passion for cleaner sources of power).

2 METHODOLOGY

2.1 Research design

To address the research question, we interviewed senior managers involved in recruitment. In 'elite' interviews, interviewees are selected for their leadership roles and access to company information (Empson 2018). Because interviewees are often under pressure of time, the interview protocols should be short and focused (Aberbach and Rockman 2002). In addition, the interview protocol should be sufficiently opened-ended to enable the interviewee to structure his or her own account of the issue under investigation (Empson 2018). In this study, some interviewees were senior managers of large international companies, while others were owners of smaller businesses that operated regionally. We ensured that there was gender representivity, representation from the global South and the global North, as well as from start-up companies and more established companies.

Table 2. Interviewee matrix

No	Interviewee	Gender	Engineering	Scope	Position	Country
1	Atfa	F	Computer	National	Owner	Rwanda
2	Benicio	M	Electronic	National	Manager	Mexico
3	Chandrak	M	Chemical	Multinational	Division Head	India
4	Daniella	F	Construction	National	Partner	South Africa
5	Esther	F	Agriculture	Local	Owner	South Africa
6	Fadhili	M	Electrical	National	Owner	Kenya
7	Gary	M	Electronic	Multinational	Division Head	United Kingdom
8	Hans	M	Mechanical	Multinational	Division Head	Germany
9	Ivan	M	Chemical	National	Manager	Russia
10	Jean	F	Mechanical	Multinational	Division Head	United States
11	Karin	F	Construction	National	Division Head	Sweden
12	Lucas	M	Electrical	National	Division Head	Greece

The researchers studied information on the companies' websites, including job advertisements prior to the interviews. This prepared them for a focussed engagement with participants in the limited time available. The main question probed was: 'When you hire graduates for your company, are there particular qualifications and skills sets that you are looking for?' Prompts were used to probe the participants' responses, or to elicit more detailed explanations. Interviews were conducted on the Zoom platform and the interviews were audio-recorded, transcribed, and anonymised. Ethical clearance for the research activities was obtained from the lead institution, and informed consent was obtained from all participants. Consent to record the interview was obtained prior to the start of the interview.

2.2 Data analysis

There were two levels of data analysis: the first level required *in vivo* coding of the data (drawing on the actual words and descriptions of the participants); the second level required theoretical coding, drawing on the categories of Specialization that were adapted for this study (Table 1).

3 RESULTS

Employers valued a wide range of technical and social skills – from cutting edge digital technologies to interdisciplinary teamwork. The technical and social skills that employers valued are clustered into categories below, based on the *in vivo* coding.

3.1 'The digital tools of their jobs'

None of companies included in the study had fully developed their own technological systems and most employers expected engineering graduates to contribute to the adaptation and efficient use of the digital and other technologies that they had invested in. Employers valued graduates' technical engineering knowledge, and understood university qualifications to be indicators of these achievements. Chandrak, a regional manager of a chemical engineering company, expected chemical engineering graduates to 'have knowledge of quantum computing, AI, robotics, real-time data – the digital tools of their jobs.' Hans, the manager of an automotive engineering plant, expected graduates to be 'highly competent in automated production technologies.' University degrees were valued, even in companies that prided themselves on being 'artisanal', such as the brewery that Ivan managed. He explained that the implementation of automated processes increased the need for university graduates. As Benico, in a banking context, put it: 'We don't all need to be AI experts ... but we all need to have some of the skills that the AI environment demands' (Benico).

3.2 'Respect for the old ways'

In workplaces that traditionally employed artisanal workers, university graduates were expected to respect 'the old ways', even while having a 'passion for new technologies'. For example, engineers needed to 'respect' the traditional brew masters and had to answer to them. In the case of farm manager, Esther, agricultural graduates were expected to respect the practical knowledge of farm labourers as they had 'a lifetime of working with grape production and they [knew] things that a young graduate with a fancy degree [didn't] have a clue about.'

3.3 'Do their eyes light up?'

All the companies in the study had introduced digital technologies into their work practices, they therefore expected graduates to be enthusiastic about these innovations. Esther described 'ideal' employees as 'excited about the future, they love the tech – and they want to go places with us.' Karin was looking for graduates 'who are driven and committed to innovation and change in the building industry'. While participants wanted to hire graduates that would contribute to the company, they were also keen to find recruits who were passionate about the possibilities of advanced technologies. In the extract below, Atfa demonstrates the convergence of passion for the company, for the industry, and for advanced technologies:

> I can identify the person who will be able to contribute to our company's vision. I will usually ask a question about a new technology and wait for the response. The person whose eyes light up and can't stop speaking about it, well that's my next hire.

Several participants required new recruits to be 'passionate', not only about the new technologies, but about how these could be used, for example, to mitigate climate change. For Lucas, the ideal graduate 'must be driven by the environmental sustainability of wind generated power'. And if you are going to work in the brewing industry, as Ivan pointed out, 'it helps if you enjoy the product.'

3.4 'The digital twin'

Hans used the term 'digital twin' to explain a type of remote technical assistance in which the engineer had a digital twin of the machine supplied to a customer, who had the actual machine and connected digitally to the engineer or other operator, as if she or he was 'standing right next to them.' Several companies used digital technologies in similar ways. In the banking context Gary explained that the ‘exponential growth in the number of clients’ and the increasing ‘complexity of the services they required’ meant they were ‘changing from traditional personal banking and advising to harnessing the power of the new digital technologies, AI, data analytics, cyber security…’ Employers were looking for graduates who could work comfortably in these digital spaces.

3.5 ‘The last mile’

The term ‘the last mile’ was used to describe that part of the business operation that was not yet fully digitised or automated, as Fadhile explained: ‘it’s about pushing that digital environment further into the real environment’. In ‘the last mile’ advanced technologies were not yet available, thus basic technologies or traditional ways of marketing, installing, or implementing had to be used. For Chandrak, the last mile was the engineer in the field. Despite fieldworkers’ access to ‘drones and robots that augment their capacities [to] carry out many tasks in the pipeline that are too dangerous for a person to undertake,’ there remained a gap in which work was not yet automated and the fieldworker needed ‘to consult a senior engineer [and] obtain the necessary authorisations.’ For Esther, the last mile was that part of farm work that robotic harvesters and drones could not do: ‘robots can pick and the drones can scan but they don’t do the regular maintenance of the vines’. Addressing the ‘last mile’ usually involved employees using basic technologies in some areas of work.

3.6 ‘Everything’s connected’

The workplaces employed technologies that communicated with one another and connected people, machines, products, services, and systems. The nature of this interconnectedness was evident beyond the technical in the interdisciplinary nature of the work, the complexity of processes, and the diversity of work teams in terms of nationalities, gender, and educational levels. Installing wind turbines, as Lucas explained, was ‘the end point of a very long process [and] expertise and experience at all the stages of the process’ were needed. Inter-disciplinary and inter-professional collaboration has always characterised workplaces that employ university graduates, however what was notable was the increasing hybridity of workplaces, in particular the extent to which human-machine interactions had become commonplace. Esther’s description of how farm workers accepted robotic harvesters is a case in point:

> … they had training in working alongside the robots … a couple of years down the line they are a lot more comfortable with them … I heard our foreman explaining the situation to some new staff ... he told them that [there’s a machine on the team] [translated from Afrikaans] ... and they were ... ja well no fine.

The introduction of advanced technologies in Karin’s building company saw ‘a change in professional roles’, in particular a role reversal between architects and builders, while the introduction of automation had the unexpected, but welcome, effect of bringing more women into construction: ‘We have used machine strength to make the workplace more equitable’ (Karin).

3.7 Discussion

The study identified three levels of technical skills valued by employers: 1) the use of non-specialised digital technologies (often for communication); 2) the use of advanced digital technologies to accomplish work; and 3) the design and development of advanced technologies associated with Industry 4.0, such as robotics, artificial intelligence, the Internet of Things, cloud computing, and so on. The study also identified three kinds of social skills in companies that used the technologies associated with Industry 4.0: 1) Some changes in personal dispositions and interpersonal relationships, 2) more complex changes in the ways in which work was accomplished, and 3) the transformation of workplace relationships.

As new technologies entered workplaces, the need for technical engineering knowledge increased, for example, the artisan brew masters were trained to use scientific data to confirm or develop their brewing abilities. Although disciplinary knowledge was not always required to use specialised digital technologies, the need for technical skills strengthened when specialised digital technologies were introduced, and training was usually required (Table 3). An example is the chemical engineer using a specialised robot to inspect an area of a pipeline. Operating the robot required training in advanced technical skills, beyond the engineer’s specialist rheology knowledge. At the highest level, engineering knowledge for the design and/or adaptation of specialised technologies was valued. None of the companies included in the study had designed their own digitised systems, but most companies expected that graduates would contribute to their adaptation and efficient usage.

Table 3. Emerging socio-technical integration

Socio-technical	Description	Example from the data
Level 3	Graduates collaborate in interdisciplinary and transdisciplinary teams to innovate in interconnected digital and cyber-physical environments.	I want to see these young engineers telling us about future directions of technology (Chandrak).
Level 2	Graduates work comfortably with colleagues and clients in a digitised environment.	... for our customers it's as if the [Name of Company] operator is standing right next to them ... so the operators need to understand and anticipate the needs of the customers ... and it all starts with the digital twin (Hans).
Level 1	Graduates value the ways in which digital and related technologies can address engineering and societal challenges.	They must know about the range of technologies that we work with - and how we can reduce our carbon footprint … from planning to building to occupation and sustainability into the future (Daniella).

The use a robotic pipeline inspector did not change the need for a junior engineer doing fieldwork to consult with senior engineers, although the mode of consultation changed considerably. The field inspector could send digital images to the senior engineer, rather than return to the office for a face-to-face meeting (Level 1). Some work practices changed more noticeably. For example, in the automotive foundry both specialised and non-specialised technologies were used. Digital twins were made possible by the images produced by specialist machines, but non-specialised digital technologies (e.g., mobile phones or tablets) were used to connect remote operators with clients (Level 2). In some cases, digital technologies involved considerable changes in professional skills and the disruptions of social hierarchies. For example, the use of robots in the construction company enabled more women to enter the construction field (Level 3).

3.3 Conclusion: What do employers value in graduates?

In addressing the research question 'What technical and social skills do employers in digitised/cyber-physical workplaces value in engineering graduates?' the study identified three broad domains in which the integration of socio-technical skills emerged: 1) enthusiasm for, and appreciation of, the role of digital and other advanced technologies in addressing engineering and societal challenges; 2) teamwork and/or client support in digitised environments; and 3) interdisciplinary and transdisciplinary collaboration for technological innovation.

Many of the findings of this study are supported by the literature. For example, the increasing need for technical skills in digitised workplaces (Jensen 2018). In the literature, 'respect for the old ways' includes enduring professional skills and values, such as 'emotional intelligence, empathy, altruism, and reciprocity' (Aoun, 2017). The literature also supported some of the more specific findings on the importance of new graduates' 'enthusiasm' for new technologies (Rangraz and Pareto, 2020). While the existing literature implies that workplaces with digital and other advanced technologies will impact professional practices in many ways (Frank et al. 2019), these have not always been specified or studied in-depth. This study has contributed to an understanding that social skills are not 'added onto' technical skills but are deeply integrated with them.

This study contributes a theorised account of the technical and social skills that employers value in engineering graduates entering into their industries. In particular, the study contributes to a deeper understanding of the interconnections between digitised work practices and the cultivation of social skills and dispositions. The employers highlighted a need for stronger university/industry collaboration in engineering education. Atfa provided a rationale: 'We are trying to build this industry and [universities] are producing the professionals for this industry, so obviously we must work together'. Some participants felt that in many ways engineering practice was ahead of engineering education. Other participants wanted to bring theory and practice into a space of mutual learning. Several of the interviewees clearly valued engineering qualifications but tried to explain the particular combinations of scientific knowledge and social dispositions that they felt made a difference to the employability of graduates. As Atfa put it: ‘there is a false dichotomy between soft skills and hard skills’. The study highlighted employers’ perspectives of how particular integrations of technical and social skills enabled graduates to successfully transition to practice in digital environments. While more detailed studies of how digital and cyber-physical technologies impact engineering practice in specific fields and industries are needed, the study points to gaps between practices in digitised environments and engineering education. The results thus have implications engineering educators. In particular, the study identified an emerging a shift from a skills discourse that assumes a separation between social and technical skills towards one that captures the dynamics of socio-technical integration.

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RESILIENCE-RELATED COMPETENCIES IN ENGINEERING EDUCATION – MAPPING ABET, EUR-ACE AND CDIO CRITERIA

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ABSTRACT

In view of the increasing intensity and frequency of natural disasters due to climate change, engineers need to be able to design systems and infrastructures that are resilient to disruptions. Resilience, here, describes the ability of systems to not only be prepared for sudden crises and to recover from these, but also to learn in order to build adaptive capacity. However, research has shown that there is a lack of system resilience and related competencies in engineering education at various levels. First, there are only a few studies that address resilience on a system level in engineering education. Second, studies on teaching experiences show that engineering students have little knowledge about resilience and skills to design resilient systems. And third, an analysis of engineering programs in Europe has shown that resilience-related topics and competencies are rarely addressed in curricula. Based on these results this study will explore the extent to which resilience-related competences are included in accreditation guidelines and frameworks such as ABET, EUR-ACE and the CDIO Syllabus. This will then be discussed in the context of previous research on the qualification objectives of engineering degree programs, questioning to what extent these are consistent with accreditation guidelines and frameworks regarding

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systems resilience. This provides a baseline for recommendations for curriculum development in engineering.

1 INTRODUCTION

In view of the increasing intensity and frequency of natural disasters due to climate change, war, political instability and other sources of volatility, engineers need to be able to design systems and infrastructures that can deal with disruptions. Doing so is frequently subsumed under the term resilience, which describes the ability "to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events" (National Research Council 2012). While many definitions of resilience exist, they all have aspects in common, such as the ability of a system, community or individual to recover, to prepare and to adapt to disturbances, to deal and live with change and uncertainty as well as lifelong learning in the context of failure. Moreover, resilience is concerned with analyzing and building mechanisms to cope with those disturbances in order to provide adaptive capacity (Walker 2020, Francis and Bekera 2014, Mayar, Carmichael, and Shen 2022). Note that this is not the same as robustness, which describes "the ability to resist a disturbance by not changing", whereas the idea of learning to live with change is inherent to resilience (Walker 2020). This work primarily addresses resilience as an attribute of systems, not of the engineers who build them.

Both scientific studies and governance reports underline the relevance of resilience and the need to enable engineers to build and design adaptive systems, especially in the context of climate change (Martin et al. 2022, Pearson et al. 2018, UNESCO 2021). At the same time, research has shown that there is a lack of system resilience and related competencies in engineering education at various levels (Winkens and Leicht-Scholten 2023a, b). In line with that, case studies about resilience in engineering education have shown that students have little knowledge about resilience and difficulties in applying the concept to complex real-world problems (Rokooei, Vahedifard, and Belay 2022, Winkens and Leicht-Scholten 2022). Even when it is covered, system resilience is mostly addressed as a teaching content, i.e., teaching engineering students about resilience or the design of resilient infrastructure (Winkens and Leicht-Scholten 2023b).

This gap between research, government demands and educational practice can be addressed at several levels: A previous study focused on resilience-related competencies in engineering study programs. Five large European technical universities were chosen, a qualitative analysis was then based on selected key terms and competencies relating to system resilience with regard to the learning/qualification outcomes of the respective study programs. Findings showed a lack of resilience-related competencies in most study programs, with only a few programs explicitly addressing system resilience (Winkens and Leicht-Scholten 2023a).

In this follow-up work, the previous analysis is expanded to the ABET criteria, EUR-ACE framework standards for accreditation of engineering programs and the CDIO Syllabus, as all three are relevant in that they are meant to serve as a blueprint for learning/qualification outcomes of study programs. Thus, looking at them is important when trying to identify reasons for the lack of resilience in teaching and curricula.

This leads to the following research question: How (far) are resilience-related competencies addressed in engineering education standards and guidelines on European and international level, such as EUR-ACE, ABET and CDIO?

The results are then discussed in the context of previous results on resilience competencies in engineering education research and learning/qualification outcomes of study programs.

2 METHODOLOGY

2.1 Research Framework

In the following, the previous described analysis will be expanded to the ABET criteria, EUR-ACE framework standards for accreditation of engineering programs and the CDIO Syllabus. This allows us to consider different levels of engineering education.

ABET and EUR-ACE were chosen for analysis as they represent requirements and standards for engineering curricula in two different continents. The ABET criteria for accrediting engineering programs in the US include seven general students, i.e., learning/qualification outcomes (ref. Criterion 3) for all study programs and additional discipline-oriented outcomes (ABET 2021). These include complex problem solving, engineering design, communication, recognizing ethical and professional responsibilities, collaboration and teamwork, experimentation and the acquisition of new knowledge.

The EUR-ACE framework formulates standards and guidelines for engineering programs in the European Higher Education Area (EHEA). In this framework, according to the Bologna process program outcomes for Bachelor and Master degrees are formulated, which are “to be considered as the ‘minimum threshold’ […] and to be fulfilled in order to assure the quality of engineering programmes.” (ENAEE 2021). The EUR-ACE program outcomes are categorized in eight learning areas: knowledge and understanding, engineering analysis, engineering design, investigations, engineering practice, making judgements, communication and team-working, and lifelong learning (ENAEE 2021).

The CDIO (Conceive, Design, Implement and Operate) Syllabus is a reference framework for designing engineering curricula and formulating learning outcomes that is both detailed and broad to ensure general applicability. It was based on a systematic process by the education initiative CDIO. The syllabus contains a detailed list of topics which “indicate desirable competences of graduating engineers” (Malmqvist et al. 2022). However, it is not prescriptive, but “intended to be comprehensive” (Malmqvist et al. 2022). Accordingly, the aim is not to address every topic of the syllabus in an engineering program, but to be able to be adapted towards a syllabus for specific program outcomes and requirements. Research showed that engineering programs developed on the syllabus would also meet other accreditation standards, such as ABET or EUR-ACE (Malmqvist 2009, Crawley et al. 2011). This is because the syllabus contains more detail and covers the whole lifecycle of a process, system or product, i.e., it “reflects a more encompassing view of engineering” than other frameworks, such as ABET (Crawley et al. 2011).

2.2 Identification of resilience-related key terms and competencies

The analysis is based on a deductive approach, by applying the already developed conceptual framework for resilience-related competences (Winkens and Leicht-Scholten 2021, 2023a) and specifically searching for the terms and competencies contained in the documents described above. Based on and derived from several definitions of resilience, these key terms and competencies are: anticipating, adapting, absorbing, preparing, recovering, responding, transforming, learning (from failure), recognizing/monitoring threats, dealing with uncertainty and complexity, developing with change and system thinking (for further details see Winkens and Leicht-Scholten 2023a).

Moreover, we searched for the term “resilience” itself as well as resilience-related topics and synonyms such as disaster, threat, hazard, risk, unknown, ambiguity or volatility. In order not to neglect any relevant content that might not contain the search terms described above but could still characterize resilience, we additionally searched the documents inductively for underlying resilience aspects. Both approaches were done by two researchers, independently, and then combined.

3 RESULTS AND DISCUSSION

The analysis of the three frameworks resulted in an assignment of several resilience-related competencies. Most of the above-described 13 competencies were categorized, except for absorbing, recovering and transforming. Moreover, resilience itself was only mentioned once in all analyzed documents, i.e., in the CDIO Syllabus (2.3.2 “Emergence and Interactions in Systems”). Here, resilience was mentioned as a keyword besides, e.g., tipping points and adaptation. For CDIO, we differentiate between the 2.0 and 3.0 versions of the syllabus, as many additional items were added in the latter. Furthermore, some items are only part of the extended version of the 3.0 Syllabus. For ABET, we analyzed the general student outcomes (Criterion 3) and all listed study programs. For EUR-ACE, we differentiate between Bachelor and Master level according to the standards and guidelines.

It must be noted that in some cases we categorized a single item or learning outcome twice. This was done because in these cases one item includes explicit references to two resilience-related competencies, such as the “ability to develop, to design new and *complex products* (devices, artefacts, etc.), *processes and systems*, with *specifications incompletely defined and/or competing*” (EUR-ACE Master). Here, both dealing with uncertainty and complexity are part of the item.

The results are summarized in Table 1 and will be explained in detail in the following sub-chapters.

Table 1. Resilience-related competencies in EUR-ACE, ABET and CDIO

Framework \ Competencies	ABET**	EUR-ACE: Bachelor***	EUR-ACE: Master	CDIO 2.0	CDIO 3.0 Additions
Anticipating				4.3.5	4.1.6, 4.1.7, 4.2.6, 4.4.1, 5.1.2*, 5.1.7*
Adapting				2.3.2, 2.4.3	4.3.2, 4.3.4, 5.1.8*
Absorbing					
Preparing	CYS, FRP				4.2.1
Recovering					
Responding				2.4.3	4.1.2, 4.2.1
Transforming					
Learning (from failure)	General Outcomes	x	x	2.2.4, 2.4.7	2.4.7
Recognizing/ monitoring threats	CYS, CBB	x	x	2.1.5, 4.2.6	4.2.6, 4.3.1, 5.1.6*, 5.1.7*
Dealing with uncertainty	ENV, PET, CIV, SYS, CON		3x	2.1.1, 2.1.4, 2.2.2, 2.2.4, 2.4.1, 4.5.2	2.2.3, 2.3.1, 2.4.1, 4.3.2, 5.1.7*
Dealing with complexity	General Outcomes, CYS, ECT, MIN, NCR, SFT, SRV, SYS	5x	7x	2.1.2	4.1.2, 5.1.7*
Developing with change		x	x	2.3.4, 4.3.5, 4.6.4	2.4.6, 4.3.1, 4.3.2, 4.4.1, 4.6.3
System thinking	CYS, ENV, PET, CIV, SYS, ARC, BIM, CON, EMG, EME, IND, MEX, NAV, OPT		x	2.3: 2.3.1, 2.3.2, 2.3.3, 2.3.4, 4.4.3, 4.5.5	2.3.1, 2.3.2, 4.3.2, 4.3.3, 4.3.4, 4.3.6, 4.4.6, 4.5.5, 5.1.8*

* indicates items from the CDIO Extended Syllabus
** Abbreviations for ABET engineering program categories: CYS – Cybersecurity, ENV – Environmental, PET – Petroleum, CIV - Civil Engineering, ECT – Electrical, Computer, Communications, Telecommunication(s), MIN – Mining, NCR – Nuclear, Radiological, SFT – Software, SRV – Surveying, SYS – Systems, CBB – Chemical, Biochemical, Biomolecular, ARC – Architectural, BIM – Bioengineering, Biomedical, CON – Construction, EMG – Engineering Management, EME – Engineering Mechanics, IND – Industrial Engineering, MEC – Mechanical, NAV – Naval Architecture, Marine Engineering, Ocean Engineering, OPT – Optical, Photonic, FRP – Fire Protection
*** x indicates a mention, 3x/5x/7x indicate multiple mentions

3.1 ABET

The ABET criteria contain several references to resilience-related competencies that were most pronounced for the system thinking category and complex problem solving. However, by themselves these are insufficient to categorize resilience, as the abilities to solve complex problems and system thinking alone do not enable engineers to design resilient systems (Winkens and Leicht-Scholten 2021), since aspects of adaptation, anticipation and learning are also crucial. In total, six out of the 13 resilience-related competencies were categorized (see Table 1).

Considering each study program, Cybersecurity has the most explicit and multiple references to resilience. Here, students are not only to deal with complex systems, but to do so and to maintain operations in the presence of risks and threats. Moreover, they are to test and protect complex devices and systems which – in combination – represents both anticipating and learning from failure. Similar, in Environmental Engineering, one focus is to design systems that includes consideration of risk and uncertainty. Another course, Fire Protection, inherently deals with the design of systems in order to protect the public from the impacts of fire, i.e., a threat/hazard. Degree programs such as Civil, Systems and Construction Engineering cover the statistical management of risk and uncertainty. However, all three of them are devoid of references to adaptation and/or learning from disaster. Finally, in some cases the opposite of uncertainty is addressed, e.g., Data science and analysis calls for conformance of precision and accuracy, which implicitly addresses uncertainty.

3.2 EUR-ACE

The EUR-ACE framework differentiates between Bachelor and Master abilities. In Bachelor programs, a strong focus is set on complex problem solving. At the Master’s level, students should demonstrate the ability to solve complex and unfamiliar problems, which can also be incompletely defined or have competing specifications. Both Bachelor’s and Master’s students have to engage in lifelong learning and to deal with risk and change management. Further, Master’s students are to formulate judgements with incomplete or limited information, to handle complexity and to develop and design new and complex products or systems. Combining those abilities, a strong resilience reference can be found in EUR-ACE Master’s requirements that systematically builds on the Bachelor level’s learning outcomes. Here, six out of the 13 categories with regard to resilience-related competencies were assigned, focusing on learning, recognizing/monitoring threats, dealing with uncertainty and complexity, developing with change and system thinking (see Table 1).

3.3 CDIO

The CDIO Syllabus 3.0 is structured into five sections and subsections with more detailed descriptions. As there were major changes between the 2.0 and recent 3.0. version, with the latter focusing on increasing complexity and several “change drivers” in the context of a VUCA (volatile, uncertain, complex and ambiguous) world, both are discussed here. Notably, the third version was revised with regard to the topics sustainability, digitalization and acceleration (Malmqvist et al. 2022).

Several aspects of resilience are covered in the Syllabus, both on an overall category level and in the category subtopics. For example, system thinking (2.3) is an explicit category, including the subcategories thinking holistically (2.3.1), and emergence and interactions in systems (2.3.2). Moreover, subcategory 2.4.1 represents the initiative and willingness to make decisions in the face of uncertainty and 2.4.3 adaptability, resourcefulness and flexibility. Looking at the next level of detail, i.e., the individual topics contained in the categories, there are several assignments to the pre-defined resilience categories, such as the ability to anticipate, adapt, dealing with uncertainty and complexity as well as recognizing/monitoring threats. The only competency categories which were not assigned are absorbing, recovering and transforming.

In the updated 3.0 version of the CDIO Syllabus, system thinking is covered more holistically by integrating not only a deterministic view on technical systems, but also including socio-technical interactions and the consideration of uncertainty and complexity (Malmqvist et al. 2022). This is also mirrored in the results of the analysis, as most of the categorized items are part of the newer 3.0 version of the Syllabus. As noted above, resilience itself was mentioned here as a topic besides adaptation, as part of the subcategory 2.3.2 emergence and interactions in systems.

The CDIO Syllabus also contains a focus on anticipatory competencies. This is especially the case for the fourth ("CDIO") category of the Syllabus, where, for example 4.1.6 (visions of the future) contains aspects of possible and probable scenario planning as well as long- and short-term concepts and 4.3.4 (system engineering, modeling and interfaces) includes system designs that are non-deterministic, continue to learn and modify themselves during operation. These descriptions inherently describe resilience in a system context. At the same time, the categorized items in the Syllabus are in some cases so explicitly referring to resilience that some items were difficult to assign to only one competency category. See for example the subcategory 4.3.2 (understanding needs and setting goals) which contains the competencies to allocate "margins, responding to change and handling unknown or unanticipated requirements during the lifecycle of a design". This outcome simultaneously refers to adapting, learning and developing with change (see Table 1).

3.4 Discussion

Compared to our previous study on resilience-related competencies in European engineering study programs (Winkens and Leicht-Scholten 2023a), the overall picture is more heterogenous. There, most study programs address dealing with complexity in the context of solving complex problems as well as system thinking. These competencies are central to engineers' toolkit, but in terms of resilience they are not sufficient to design resilient systems. These results are also mirrored in the ABET Criteria: The general requirements contain no competencies that go beyond dealing with systems and solving complex problems, which are a staple of engineering itself. However, some degree programs contain strong references to resilience. The EUR-ACE framework is similar to that at the Bachelor's level, however they still include lifelong learning, and risk and change management. At the Master's level, EUR-ACE requires a stronger set of resilience-related competencies for graduates then it is the case with ABET, especially with regard to the handling of incomplete or competing information.

In comparison, the 2.0 CDIO Syllabus already contains strong resilience reference. The 3.0 Syllabus builds on that and calls for a broad range of competencies suitable to prepare engineers for designing resilient systems. Compared to the ABET and EUR-ACE outcomes, it is notable that not only were more resilience-related competencies categorized in the CDIO Syllabus, but that the latter also contains a focus on anticipatory competencies (which are inherent to and necessary for resilience), as discussed before. However, as already discussed by Malmqvist (2009) and Crawley et al. (2011), a comparison of the proficiency levels of the three analyzed frameworks is difficult. But, as, at the same time, the CDIO Syllabus represents a more holistic view of engineering than ABET and EUR-ACE, is more detailed and also includes the outcomes of other reference frameworks, we still find the comparison to be purposeful.

In the context of our previous results on the lack of resilience-related competencies in European university study programs (Winkens and Leicht-Scholten 2023a), these results are unexpected especially with respect to EUR-ACE: While standard calls for strong abilities in the context of systems resilience, few study programs contain those as learning outcomes. This exposes a clear gap between accreditation requirements and university practice in formulating learning outcomes, an issue which is already well reported (e.g., Passow and Passow 2017, Shuman, Besterfield-Sacre, and McGourty 2005). Whether the gap in our case is due to the selected study programs in the previous study, a delay in implementation, or an example for a systemic issue remains an open question which needs further research. Similarly, for resilience-related competencies, there is no evidence whether and/or to what extent the ABET criteria are consistently implemented in practice, which is also a promising avenue for a follow-up study. Finally, this work indicates that consistently implementing the CDIO Syllabus as a basis for an engineering program could serve to address resilience-related competencies.

4 SUMMARY

All three reference frameworks emphasize solving complex problems as a key element of engineering education, which also contributes to designing resilient systems. Beyond that a small number of ABET courses of study contain a strong reference to resilience competencies and/or more frequently dealing with uncertainty. EUR-ACE is more comprehensive in this regard, but at least for the courses considered in our previous work on resilience-related competencies in European university study programs (Winkens and Leicht-Scholten 2023a), this does not appear to trickle down into course level learning outcomes. The CDIO Syllabus provides an extensive coverage of resilience-related competencies. Notably, this does not only include dealing with complex systems under uncertainty, but also explicitly and repeatedly addresses anticipatory competencies and learning (from failure), which are necessary competencies for designing resilient systems. Finally, the results show that beyond additional research, closing the gap between the Engineering Education Research community, accreditation and actual course content and learning outcomes remains both a major challenge and opportunity for engineering education.

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MAPPING THE ENGINEERING EDUCATION RESEARCH LANDSCAPES ACROSS EUROPE

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ABSTRACT

The growth of Engineering Education Research (EER) has led to claims about it becoming a globally connected field of inquiry. This paper presents data on the development of EER within seven European countries, with the aim of contributing

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towards understanding of the field. Data was collected from participants of a workshop held at the SEFI 2022 Annual Conference which was entitled “Mapping Engineering Education Research in Europe”. Participants were asked to comment on the presence of formal research groups and PhD Programmes, as well as incentives and funding opportunities within the context. In most countries, there was a reported absence of formal EER groups and EER PhD programmes and in some cases, PhDs focusing on EER were included within general science and engineering programmes. In most cases incentives were associated with teaching awards and interventions and funding opportunities appeared to be small and isolated. In few cases was EER considered to be as valued as disciplinary research. The overall portrait that emerges from the data collected suggests that EER within European countries does not benefit from a national support infrastructure, but rather is typically carried out by individuals or small groups of researchers.

1 INTRODUCTION

Research focused on development of EER has grown over previous decades. For example, observational data collected at the International Conference on Research in Engineering Education (ICREE) was used to examine how EER is conceptualized as a discipline, community of practice, and/or field (Jesiek, Newswander, and Borrego 2009). Elsewhere, the state of EER has been described (Froyd and Lohmann 2014) using Fensham’s (Fensham 2014) criteria for evaluating maturity levels of fields of disciplinary-based education research.

Comparative methodologies have been used to consider approaches to EER within different global contexts (Jesiek, Borrego, and Beddoes 2010; Jesiek, Borrego, and Beddoes; Streveler and Smith 2010), and EER in the USA has been compared to that in Northern and Central Europe, the authors claiming that understanding the perspectives of those within other contexts, particularly regarding what constitutes quality, is needed for development of EER (Borrego and Bernhard 2011).

Although work primarily concentrates on the US context, several papers have now been published which focus on EER within different European countries including: Portugal (Sorby et al. 2014; van Hattum-Janssen et al. 2015) Ireland (Sorby et al. 2014; Wint et al. 2022); the UK (Nyamapfene and Williams 2017; Shawcross and Ridgman 2013; Wint and Nyamapfene 2022; Wint et al. 2022a); and within three Nordic Countries (Edström et al. 2018); as well as in Europe as a whole (Bernhard 2018). However, there is a need for work comparing EER between individual countries in Europe and the authors believe that the SEFI community is a potentially valuable source of relevant data at country level.

The aim of this work is to establish a baseline position with respect to EER within Europe, and to make use of findings to recommend actions at a European level. In this paper we thus compare the development of EER within seven different European countries: Belgium, Demark; Finland; Ireland; Italy; the Netherlands; and the UK. In so doing, we present data collected from participants of a workshop held at the SEFI 2022 Annual Conference (Wint et al. 2022b) which focused on contextual factors which influence development of EER in countries across Europe.

2 METHODOLOGY

Data was collected from participants of a workshop held at the SEFI 2022 Annual Conference which was entitled “Mapping Engineering Education Research in Europe” (Wint et al. 2022b). During one of the activities, participants were asked to write comments about the presence of formal research groups and PhD Programmes, as well as both national and institutional incentives and funding opportunities within their context. They were also asked for any other information they felt was relevant to understand EER within their country. Answers were collected at the end of the workshop. 12 people from seven different countries provided answers to the questions asked. Of these, seven participants from six different countries supplied contact details and were emailed a copy of their answers, alongside our interpretation and any further questions we had regarding their answers. They were asked to recommend anybody they thought we should contact for further information about EER within their context. Through a snowball sampling approach, a further six participants from three different countries were contacted, of which three replied, all from the same country.

The study reflects the views of a small number of self-selected participants and can therefore be considered subject to selection bias. An advertised workshop aim was to provide “insight into ways to support development of EER in the future”, and it may therefore be reasonable to propose that those who took part wanted to contribute towards the growth of EER and may possibly focus more heavily on negative aspects of EER within their context. Future work may benefit from an approach that includes a more representative sample that includes the audience of the research as well as researchers within other complementary fields such as social sciences or education and other stakeholder parties such as funding bodies and editors of research journals. Another limitation of the study relates to the fact that it takes an ‘insider’ view of the state of EER within each context. It would also be of interest to focus identifying any relationships between contextual factors and research output, for example via use of scientometric analysis (Wint et al. 2022a).

3 RESULTS

The findings for each country are presented below and summarised in Table 1.

3.1 Belgium

Aside from one formal group (Leuven Engineering and Science Education Center, KU Leuven), participants only acknowledged ‘loose’ departmental centres. Participants were not aware of PhD programmes in EER, only science and technology. Whilst there was believed to be a national focus on STEM education, this did not extend to education research. There was a lack of national incentives or funding, but it was possible to receive institutional funding, albeit challenging.

3.2 Denmark

In Denmark, participants did not comment on the presence of formal research groups but did express concerns that formal structures may discourage entrants from technical research. PhDs in EER were typically considered to be obtained through, and drive, publication. EER was thought to be valued as much as disciplinary research at an institutional level and philanthropic funding was mentioned as being available at a national level. Participants referenced a national “points-based system” (which is taken here to mean the Danish bibliometric research indicator or BFI), Denmark’s national system for measuring research output, which forms part of a performance-based model of distribution of the new block grant based on production of research-based publications (Deutz et al. 2021). The system makes use of a tiered rating of publication channels (e.g., peer reviewed journals and publication houses) and assumes articles published in a given journal are equal in quality, or books published by the same publisher are of equal quality (Deutz et al. 2021). A new political agreement in December 2021 saw the termination of the BFI, with participants commenting that the impact of this on EER funding was unknown.

3.3 Finland

The Professional Growth and Learning (PGL) Research Group (Tampere University) was the only group identified. The group is led by Professor Petri Nokelainen who was believed to be the only EER professor in Finland. Although the group was thought to focus primarily on vocational education, they were known to publish EER, primarily within behavioural science journals. As highlighted previously, computing education research appears to be much stronger than EER in Finland (Edström et al. 2018). Groups included The Learning and Technology Group (LeTech) and that of Computing Education Research and Educational Technology (both at Aalto University and led by Professor Lauri Malmi). Another ‘loose’ group, focused on computer science education research, was claimed to exist at the University of Turku. A network of researchers from different Finnish universities who focused on computer science education and the behavioural sciences, was also reported to exist. Overall EER publications were believed to be written by individuals without any formal support structures, official research groups or themes. No structured PhD programmes were identified. Some doctoral students were claimed to focus on computer science or engineering education. Incentives or sources of recognition (including funding) were not identified at either a national or institutional level.

3.4 Ireland

As reported previously (Wint et al. 2022), EER research groups were claimed to exist within the Irish context, with one participant saying formal groups were needed to achieve critical mass. There was a disagreement between participants as to whether structured PhD programmes existed, but they were considered beneficial to generate output. There were inconsistencies with respect to the degree to which EER was incentivised or recognised within institutions, with one participant claiming, “education research won't get promotion within engineering” and another (from the same institution) saying “EER is recognised reasonably”. At a national level there was no evidence of recognition or incentives, with one participant saying EER was “still a developing area”. There was believed to be “very little” and “limited” EER funding, and indeed that for interdisciplinary research, which was “difficult” to obtain.

3.5 Italy

No EER groups or PhD programmes were identified within the Italian context. However, both the META and METID (Politecnico di Milano) were mentioned, the former focusing on: epistemology; ethics of technology and engineering; philosophy of science and technology; science and technology studies (STS); and sociology of knowledge. In one university, institutional incentives included prizes for innovation in teaching, with related publications being recognised as relevant for the prize. Career path was considered to be determined by publications within a specific research area. However, EER journals were not acknowledged on lists of recommendation. Funding was believed to be an important incentive which did not exist within Italy.

3.6 Netherlands

In the Netherlands, all four technical research universities were involved in founding the 4 TU Centre for Engineering Education (4TU.CEE) which focuses on improvements and innovation within engineering education and, as such, was considered to promote EER. Groups at some of the fourteen “Research Universities” (RU) were also identified and included: Education and Learning Sciences (Wageningen University & Research) which included full professors in education and learning sciences; Eindhoven School of Education (Eindhoven University of Technology), part of the faculty of Applied Science and Science Education with 4 full professors and a number of emeritus professors with varying links to engineering education research; the Philosophy & Ethics Group at the Department of Industrial Engineering & Innovation Sciences (TU Eindhoven); TU/E innovation Space; the Department of Learning, Data-Analytics and Technology (University of Twente) with 3 full professors; The Leiden Delft Erasmus Universities Centre for Education and Learning embedded in the department of Software Technology at Faculty of Electrical Engineering, Mathematics & Computer Science (TU Delft); Science Education Research Group at the Faculty of Applied Sciences (TU Delft); PRIME (TU Delft); Research on Education Innovation at the Faculty of Architecture and the Built Environment (TU Delft); and Ethics Education for Engineers within the section Ethics & Philosophy of Technology (TU Delft). Most groups were said to conduct wider research in education and were also involved in secondary school STEM teaching. In addition, almost all other RUs were described as having educational science research groups in which higher education research and science education research, is done. In addition, there were also reported to be a few stand-alone engineering education researchers who supervise PhD students. Groups were also identified within the University of Applied Sciences (UAS) including: one at Utrecht UAS, who focused on Vocational Engineering Education (VET); and the Sustainable Talent Development Group (The Hague University of Applied Sciences).

The 4TU.CEE was said to have a structured PhD programme with several themes. Clusters of PhDs existed within some of the RU education groups, but stand-alone PhD researchers who did their PhD on an engineering education topic in a conventional engineering research group also existed. They were typically cited as having supervisors from two fields, one engineering specialist and one (engineering) education specialist. The PhD degree earned was reported to be dependent on the Faculty students were formally assigned to (e.g. Aerospace Engineering).

In all institutes involved in the 4TU.CEE, EER publications were said to be accepted as part of Tenure Track criteria. Incentives and recognition at an institutional level were believed to have improved since publication of Room for everyone's talent framework (VSNU, NFU, KNAW, NWO and ZonMw, 2017) which led to a programme aiming to encourage promotion of individuals on the basis of education.

National incentives included: Knowledge Sector Plans, government funding available for sectors to develop knowledge for the future; Comenius Fellowships, three level of grants for lecturers for evidence-based interventions; and the lifelong learning component in the Energy Switch Initiative funded by the province South Holland:

Funding for 4TU.CEE was reported to come from the universities involved. The centre was claimed to co-fund PhDs, innovation projects and fellowships that all focus on (practice-oriented) EER. In addition to European funding, national and regional funding sources were said to exist. For example, government funding included National Regie Orgaan Onderwijs (NRO) that has various calls related to Higher Education and EER. It was considered difficult to compete within the social sciences/education domain because of the limited funding available to them, as well as the lack of awareness of EER within the wider education field.

3.7 UK

As reported previously (Wint et al. 2022a), a small number of research groups were believed to exist within the UK and considered "instrumental in creating opportunities to bring researchers together to create a critical mass of support". There appeared to be a lack of structured EER PhD programmes, although there were individuals completing EER PhDs. However, structured programmes were considered as beneficial due to the fact that EER is "often far more aligned to social sciences than the first degrees of many people who begin to engage in EER". These issues were considered similar for staff who were thought to have little time because of the need to fulfil "the rest of their responsibilities", but who also needed support moving from a science and/or engineering background. In the case of participants who attended the workshop, EER was recognised and rewarded at an institutional level, and was considered a "strong piece of evidence for career progression", something which has been noted, particularly in the case of teaching pathway staff, previously (Wint et al. 2022a). Participants agreed that funding was limited, but also highlighted the role that institutional barriers play in preventing individuals applying for funding. For example, for many calls only those in academic posts were eligible to apply, whereas those in other positions (for example teaching support staff/teaching developers were not allowed). The same was said to be true of PhD supervision, this again limiting participants' access to resources used to conduct EER.

Table 1 Comparison of EER landscapes in eight European countries

EER Landscape	Research Groups	PhD programmes	Institutional Incentives	National Incentives
Belgium	1 formal group (LESEC, KU Leuven), 'loose' departmental centres	Only programmes in science and technology	Challenging to receive institutional funding.	Lack of national incentives/ funding. Focus on STEM but not STEM education research.
Denmark	Lack of formal research groups	Obtained through, and drive, publication	EER valued as much as disciplinary research	System for measuring research output/ distributing funding. Philanthropic funding
Finland	PGL Research Group (Tampere University). Other groups focused on computer education. EER conducted by individuals without support structures	No structured PhD programmes. Some students focused on computer science/EER	Incentives or sources of recognition (including funding) not identified	Incentives or sources of recognition (including funding) not identified
Ireland	Small number of groups, with CREATE at TU Dublin being the most established.	Some PhD opportunities exist	Small incentives. Research count towards promotion.	EER developing nationally. No specific funding. Some relevant projects receive funding.
Italy	No EER groups identified, but both META and METID (Politecnico di Milano) groups mentioned	No PhD programmes	Prizes dedicated to innovation in teaching, with related publications being recognised.	Career path determined by publications within specific research area. EER journals not acknowledged on recommendation list. Lack of funding.
Netherlands	Numerous groups identified, some associated with science education research, higher education research, secondary school STEM teaching and vocational training. All four technical research universities involved in 4TU.CEE	Structured PhD programme at 4TU.CEE. Clusters of Engineering Education PhDs within some of the education groups, stand-alone PhD researchers	In all institutes involved in the 4TU.CEE, EER publications accepted as part of Tenure Track criteria. Incentives and recognition improved since the publication of the Room for everyone's talent framework.	Knowledge Sector Plans (government funding to develop knowledge for the future). Comenius Fellowships for evidence-based interventions. 4TU.CEE funding to co-fund PhDs, innovation projects and fellowships. European funding, national and regional funding (e.g., NRO)
UK	Small number identified	Lack of structured PhD programmes	Supports progression in "teaching" roles. Small funding opportunities	Institutional barriers to applying to limited funding opportunities. Teaching awards and teaching fellowships

4 SUMMARY

This work is limited by the number of EER landscapes considered, and the possibility of participant selection bias. Future work would benefit from inclusion of a wider range of countries and participants, as well as collection of further detailed data, for example pertaining to variation in institutional incentives and rewards. Despite this, the findings suggest a consistent picture of lacking national EER infrastructures and are considered representative of the case for other European countries. Except for the Netherlands, few formal EER groups were identified. There was a lack of structured PhD programmes, with PhDs typically being 'standalone' within engineering departments or obtained via publication. Institutional recognition focused on teaching awards. In some cases, there were small funding opportunities and EER counted toward promotion. Few national funding opportunities were identified. In some contexts (Denmark, Italy, and the UK), funding was linked to research output exercises which typically did not acknowledge EER. In some countries (Ireland and the UK) the interdisciplinary nature of EER limited funding opportunities as grants were designated to educationalists or technical engineering work.

EER appears to be most developed within the Netherlands where establishment of the 4TU.CEE (which is funded by the four partner universities) appears to have contributed towards increased PhD and funding opportunities. Regional and national funding opportunities, particularly those focused on the knowledge sector and lifelong learning also appear to have helped with growth of the field. Work around career pathways also seems to be beneficial. Initiatives such as 4TU.CEE are likely to provide several benefits. It provides space for development of clear strategies that focus on national needs, as well as opportunities for collaboration and researcher development. Such approaches allow for the critical mass needed to carry out ambitious and well-structured projects with wider reaching impact and this, in turn, is more likely to attract interest from researchers from different disciplines, as well as other stakeholders such as policymakers, professional institutes and industry. Based on findings from the Netherlands, which appears to benefit from establishment of a common centre and regional/national level strategy, we recommend the creation of both national and European position papers which outline strategic priorities which align with national policy. Such approaches have been taken in contexts in which engineering education is newly emerging such as Malaysia (Alias and Williams 2011) and could be facilitated by SEFI. In the absence of external financial support, it seems clear, particularly given increased pressures placed on universities and staff, that development of EER within European countries depends upon institutional recognition, and it is thus suggested that European institutions learn from initiatives which encourage promotion of individuals on the basis of education.

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(RE)DEFINING ENGINEERS' RESILIENCE: PART I AN EXPLORATORY STUDY INTO HOW ENGINEERING EDUCATORS UNDERSTAND AND TEACH RESILIENCE

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ABSTRACT

In recent years 'resilience' has increasingly been framed as a positive attribute that can play a role in the success of university students. The need for students to develop and demonstrate resilience seems particularly pertinent within engineering education. Firstly, engineering degrees are often associated with heavy workloads. This, alongside high rates of attrition and increases in mental health issues, suggests a need for students to demonstrate resilience. Secondly, engineering degrees prepare students for a profession, and it is likely that courses place emphasis on graduate attributes such as resilience. Finally, the rate of technological advancement and societal change places additional demands on graduates to adapt to career changes.

Despite the emphasis on the benefits of demonstrating resilience, there is a lack of research focusing on how it is understood and taught within engineering education. In this work we take a qualitative approach to understanding how engineering educators

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conceptualise resilience; whether they feel a responsibility to help students develop resilience; their approach to doing this; and their general perception about the resilience levels of students. In so doing, we make use of data collected from semi-structured interviews with thirteen individuals involved in the education of engineers. Interview transcripts were analyzed using reflexive thematic analysis (RTA). We find that the conceptualisation of resilience in engineering education varies, thus impacting the design of effective interventions.

1 INTRODUCTION

'Resilience', defined by the American Psychological Association as "the process and outcome of successfully adapting to difficult or challenging life experiences, especially through mental, emotional, and behavioural flexibility and adjustment to external and internal demands" is increasingly used in relation to engineering education.

In recent years, and more noticeably since the COVID-19 pandemic (Brammer, 2020), there has been an increasing emphasis on resilience as a personal attribute that can play a positive role in the success of students within higher education (HE) (Beltman, Mansfield, and Price 2011; Brewer et al. 2019; UCAS, 2018; UNITE, 2017). Indeed, various authors have highlighted the need for resilience to be taught and promoted in order that students develop the skills necessary to navigate the workplace (Sant 2013), with studies focusing specifically on 'graduate resilience' (Morgan, 2016; Hodges 2017), 'academic resilience' (Hunsu, Carnell, and Sochackam 2021; Martin and Marsh 2006), and 'career resilience' (London 1983).

The need for students to develop and demonstrate resilience seems particularly pertinent within engineering. Firstly, the heavy workload associated with studying towards an engineering degree has been highlighted on several occasions (Armstrong 1996; Brainard, Staffin-Metz, and Gillmore 1999; Godfrey and Parker 2010; Rosenblatt and Lindell 2021; Seymour and Hewitt 1997; Stevens et al. 2007; Stevens et al. 2008). This, alongside high rates of attrition (Hunsu, Carnell and Sochacka 2021), and mental health issues (Danowitz & Beddoes, 2018), suggests a need for engineering students to demonstrate resilience. Secondly, an engineering degree, by its nature, prepares students for a profession. It is therefore likely that courses place additional emphasis on employability and graduate attributes (Lucas, Claxton and Hanson; Targetjobs). Finally, the rate of technological advancement and change in society necessitate 'career resilience' (ECITB 2020; NAE 2014; Nieusma and Johnson 1996).

In a systematic literature review on if and how engineering education research (EER) addresses resilience, Winkens and Leicht-Scholten (2023) found the term linked to engineering students as a personal attribute or to systems (e.g., infrastructure). In the case of the former, the reasons for being resilient were divided into five categories: persistence in completing studies; adapting to changes to educational settings during COVID-19; learning from failures/errors; coping with stress, adversity and challenging situations; and resilience as a desired attribute, outcome or competence.

With respect to persistence, Huerta et al. (2021) describes resilience as the "enhanced ability to manage or bounce back from stress" (p. 652), an intrapersonal, noncognitive competency that is instrumental to becoming a good engineer. Hunsu, Carnell, and Sochacka (2021) introduce the more specific term of 'academic resilience' (Martin and Marsh 2006) as a theoretical framework to explore the way in which students react to academic challenges experienced within engineering education. In their study into the attributes of engineering students, Ssegawa and Kasule (2017) list 'resiliency' as necessary for managing the self and define it as 'coping with stress'. Gesun et al. (2021) define resilience as an 'internal thriving competency' within their model of thriving within engineering education. Elsewhere, the resilience of engineering students has been linked to both self-regulation (Concannon et al. 2019*)* and self-efficacy beliefs (Anthony et al. 2016; Concannon et al. 2019*)*.

Moreover, within EER, the term is commonly used in relation to issues of equity, diversity and inclusion. For example, studies have been focused on the resilience of mature students (McGivney 2007; *S*ervant-Miklos, Dewar and Bøgelund (2021), the resilience of women (Khilji and Pumroy 2019) African American and Latino students (Samuelson and Litzlerb 2016) and black women (Ross, Huff, and Godwin 2021).

As highlighted by Winkens and Leicht-Scholten (2023), although the term is frequently used within EER, few papers detail associated competencies or concrete teaching approaches, and instead point to a lack of knowledge and understanding of associated definitions. As highlighted by Payne (2012), there are many issues associated with the existence of differences in the way such constructs are interpreted, and it appears as though further research is required so that educators are able to understand the different facets of resilience and the context in which it may be taught.

These findings are particularly relevant when considering the need for both 'top down' (e.g., communicating a clear strategy by management) and 'bottom up' (e.g., individual engagement and commitment) approaches to systematic curriculum change (Kolmos, Hadgraft and Holgaard 2016) and issues which occur in the absence of educator 'buy in'. For instance, previous research has highlighted issues faced by academics when presented with a lack of clarity on role boundaries, for example, around promoting student wellbeing (Laws and Fielder 2012). In this work the authors claimed that the combination of increasing expectations of academics' performance, as well as the institutions' slowness in responding to student needs, has led staff to avoid deep investment in their students' well-being. They highlight the need for a focus on ongoing professional development and workload allocations which include 'emotion work'.

In this work we address the gap in the literature by taking a qualitative approach to understanding how engineering educators conceptualise resilience; whether they feel a responsibility to help students in developing their resilience; their approach to doing this; and their general perception about the resilience levels of their students.

2 METHODOLOGY

2.1 Study Design

The study is situated within a qualitative research paradigm allowing and focusing on understanding the meaning participants drew from experiences over a variety of contexts. It adopts an interpretivist constructionist approach (Denzin and Lincoln 2003; Lincoln and Guba 2005; Smith 1992). In-depth semi-structured interviews were selected as the method for data collection as they provided the opportunity to explore subjective meanings, experiences, and specific details of each participant (Guba and Lincoln 1994). A semi-structured interview protocol was developed to ensure coverage of key research questions and dimensions of resilience identified in the literature, but also allowed the opportunity for the interviewer to guide the discussion in directions that had not previously been considered and/or that were interpreted as meaningful for the interviewee.

2.2 Participants

Thirteen individuals provided informed consent to participate. Participants varied in experience and came from both academic (both research and teaching focused) and professional services (e.g., employability) roles (Table 1).

Table 1. Participant Information

ID	Relevant participant information
1	White female academic with industry experience. Involved in curriculum design and student engagement.
2	White male academic acting as Employability Mentor responsible for industry placements.
3	White male academic with industrial background and involved in training of graduate engineers. Employability Mentor responsible for industry placements.
4	Arab male academic involved in internationalisation. Teaches a variety of cohorts of various sizes at different levels. Experience in the UK and internationally.
5	White male research focused professor. Teaches to small cohort sizes. Experience teaching in a variety of UK based universities.
6	White female Programme Director. Teaches variety of students at different levels
7	White male early career academic, multidisciplinary teaching
8	White male early career researcher, experienced teaching assistant and involved in supporting research students
9	White male cross discipline careers consultant
10	Chinese male research focused academic. Teaches a variety of engineering programmes and cohorts of sizes. Experience in the UK and internationally
11	White male research focus professor. Teaches small cohorts of up to 40
12	White male research focused professor. Teaches small cohorts of up to 40.
13	White female teaching focused professor with experience in industry

2.3 Procedure and data analysis

Ethical approval was obtained from Swansea University College of Engineering Ethics Committee. Online interviews lasted between 40 and 90 minutes and were conducted, recorded, and transcribed by the first author. Interview transcripts were analyzed using reflexive thematic analysis (RTA). RTA was utilised for several reasons. Firstly, it is generally considered a useful method during the study of under-researched areas. Secondly, its flexibility allows for both inductive and deductive theme generation which captures both semantic and latent meaning. Finally, it is considered a reasonably accessible method which we believe to be important when considering: 1) the varied audience of EER; and 2) a relative lack of any consensus as to acceptable theoretical frameworks or research methodologies for use within the space. The authors followed the six-stage analytical process proposed by Braun and Clarke (2006).

2.4 Limitations

A limitation of the sampling method is that participants were self-selected and thus likely to have an interest in promoting resilience. A number of participants were involved in employability activities and, at times, had a remit to teach resilience, specifically career resilience. Some participants were heavily involved in training researchers and their answers were framed by their work in this area. The majority of participants were White, and all were from UK based universities. Given the findings pertaining to cultural differences in how resilience is conceptualised, there is a need to understand resilience within engineering education in other geographical locations. It is also important to understand differences and similarities between how resilience is conceptualised, developed, and demonstrated by a range of stakeholders involved in the education of engineers. Interviews with both students and employers will therefore form the next stages of this research.

3 RESULTS

Three overarching themes were generated 1) finding the middle ground 2) boundaries and limits to what the educator can do and 3) being pulled in different directions; tensions and barriers involved in developing resilience. This paper is focused on themes 1 and 2.

3.1 Finding the middle ground

This theme is split into two subthemes and focuses on finding the middle ground in terms of A) the way in which resilience is conceptualised B) teaching of resilience.

A. *"People kept telling me that that wasn't what resilience was."*

The majority of definitions given for resilience consisted of two components: firstly, the need for failure, adversity, trauma, stress, or rejection; and secondly a reaction which allows you to overcome the issue, sometimes referred to as 'bouncing back'. In many cases resilience required 'changing', 'adapting' or not carrying on the same way. These terms were often mentioned in relation to the changing profession, world of work, capitalism and technological change, with one participant saying resilience is *"increasingly important mostly because society, driven by technology, is changing rapidly"* (11). However, there were some contradictory views regarding the relationship between resilience and change. In relation to engineering projects, one educator suggested that as *"your understanding of the problem changes"* you change your process and resilience is *"about overcoming the problem, so the product got finished, the product was made, and the product was changed*". However, they later went on to say, *"some people told me resilience was about the company staying the same, the same the shape, not changing to external forces"* (7).

The ability to undergo change and be resilient was related to having a growth/flexible or fixed/inflexible mindset, with one participant saying that resilience is developed by *“having that growth mindset and that ability to kind of learn and improve and deal with feedback and deal with obstacles”* (9), and others speaking of the role of feedback and reflection. In the majority of cases participants associated resilience with having a growth mindset. However, the same individual that questioned whether resilience involved changing or staying the same under external pressures, commented that the latter definition would be consistent with people *who “don't want to change their mind about it. they're not really open to the idea. They are very resilient”* (7), this suggesting that those with a fixed mindset are more resilient.

B. How far is too far?

There was much discussion about the extent to which resilience could be taught, with one educator claiming students naturally developed resilience as *“we are already challenging them, you know, by setting exams, assignments …you're already sort of setting them up and not everyone is going to succeed”* (4), implying further interventions may not be necessary. Other participants referred to resilience as a ‘by product’ of teamwork, problem solving, providing students with incomplete information, other professional skills, complexity, and exposure to authentic tasks. Some also spoke of helping students to develop their ability to reflect and by supporting their wellbeing and encouraging them to make *“good habits, you know…like to, de-stress and focus yourself”* (8). Others focused, not on the content taught, but rather on the way in which it was taught, saying that accessible, available, inspiring, and enthusiastic lecturers that nurture students, help with resilience.

Many considered resilience as coming from practice and experience, with one individual *saying “you develop resilience by having stuff go wrong, having setbacks in your life”* (11) and another that *“it’s just practice really…you do things that are hard, and you will learn skills from doing them that will make you more resilient”* (8). Such comments raised questions about the degree to which educators should go to help students in developing their resilience. For example, one educator involved in employability questioned, *“is it ethical at all? because that would potentially put a lot of stress on students. Can we just stress our students for the hell of it and come out of it and say, ‘you got something out of it, well done’?”* (2).

Others spoke of the risk posed to mental health. One educator questioned whether focusing on resilience is *“going to make them (students) kind of more anxious and more stressed about that, and maybe lead to a bit more than negative spiral”* (9). Another spoke of being *“careful not to, you know, not to overburden… as much as you want students to be resilient, if they're struggling, you help them”* (11).

3.2 Boundaries and limits

This theme consists of two subthemes: C) the factors that impact upon resilience and the degree to which ‘the system’ in which an individual resides limits their ability to develop resilience; and D) the types of resilience which fall under the remit of engineering educators, and the extent to which their work is boundaried.

C Resilience as highly individual but impacted by the system.

Participants identified multiple factors which influenced resilience levels, with some questioning the role of nature vs. nurture, and the role of the individual in developing their own resilience vs. the role of external factors in impacting resilience levels.

Of interest were comments regarding both how the institution and discipline may impact resilience levels. For example, when speaking about attrition of students, one educator claimed that their university was *"a bit of anomaly actually…but some people around [names institution] say it's kind of like once you get into [names institution] you stay in [names institution], like people just don't leave"* (13), this suggesting a link between resilience and university status. The discipline being studied was believed to impact upon resilience with one participant claiming the *"engineering degree is notoriously tough"* (1), and another seemingly suggesting that resilience was less important for engineers *as "students are less resilient to ideas that might upset them and do not want to discuss those ideas… it's not something I come across because that's not the nature of engineering education, is it really? To discuss nuanced political and sociological ideas. We teach things which are more or less, proven facts if you if you think about the traditional chalk and talk stuff."* (11)

There was therefore a general recognition that resilience levels were heavily impacted by context with one educator saying *"I really see resilience as not just individual. It's social, it's contextual. And I don't like it when it's used to discuss individual resilience (…) I think that's missing a bigger picture"* (1), and another that *"We're also aware of the fact that, you know resilience is a kind of holistic thing which affects your whole, you know, your whole life at university it's not just about one aspect"*(9). Others spoke about the way in which the burden of developing resilience and to change is placed on the individual rather than the system, and of how this can lead to a tolerance of adversity in the case of minoritized students: *"like women have to be resilient to be able to do, you know, to get up to the glass ceiling, right? They have to adapt and I think in many ways, we have to recognize that that's happening, you know, that people are going to keep changing the goalposts and that, there is an element of power to it, right? That those that don't have power have to be more resilient, if you like, to be able to get anywhere"* (13).

The multifaceted nature of resilience meant participants generally believed its development required personalised approaches which consider contextual factors.

D Limits of the educator

The holistic nature of resilience raised questions about boundaries to the educator's role in its development and supporting students. One participant, involved in employability, described the decision as where to draw the line, *"a tricky one, because it is a holistic thing… you can't just isolate it, and say I want to have good wellbeing within my career, because if you're not happy at work and if you're stressed at work, it does affect all of the other aspects of your life"* (9).

The 'types' of resilience that fell within the remit of educators appeared to vary depending upon their role as either a lecturer or academic mentor. Most participants mentioned the role of academic mentors, with one saying *"you get outside the* *teachings sort of remit and you see the student with their personal life and how that interacts and interferes sometimes with their academic life"* (2), and another claiming that it was easier to help students who you did not directly teach as they were worried *"if I say something it will affect my relationship with the lecturer"* (10). These quotes highlight the different roles that educators may have in different capacities of their work and reveals the complexities associated with determining the limits of their work. Other educators advocated for *"treating students as whole people"* (13). A different participant said, *"I think well because we're all humans and all humans help to develop each other and just because we're in an educational setting doesn't take away that human need to support and help each other"* (1). One participant spoke of limits to the ability to do this saying, *"it is absolutely draining… but sometimes you can't help feeling that, if a student fails, then you're failing with them…I've got to stop engaging emotionally with them…I'm the one who's going to fall apart"* (2).

4 SUMMARY AND ACKNOWLEDGMENTS

The findings suggest the existence of inconsistencies in the way resilience is conceptualised, from the ability to change to the ability to "stay the same shape". Such vast differences have implications for the way in which educators support students. Educators described varying approaches to developing resilience with some describing it as an innate part of HE or as a by-product of complexity and problem solving in engineering. Others described equipping students with tools which would allow them to be resilient. This was particularly important given the positivistic nature of engineering and student resistance to open ended problems. Such findings are consistent with the work of Nieusma and Johnson (1996) who focused on career resilience within engineering and claimed that engineering education, in fact, conveys "skills, habits and values that work against flexibility".

Participants recognised individual resilience as impacted by environmental factors including engineering culture and institution type, with some talking about the way in which the burden to change is placed on the individual rather than the system. Such concerns have also been expressed by Mahdiani and Ungar (2021) who question "whether every adverse context calls for a resilience response" In their work they provide the example of poverty, in which resilience may means adapting to the idea of meritocracy. Pawley (2018) highlights the impact of neoliberalism on minoritized students, and alludes to the levels of resiliency necessitated, proposing a shift in "burden of responsibility from individual to the institution" (Pawley 2018).

The results demonstrate inconsistencies in the way resilience is understood, conceptualised, as well as the means by which it is developed in students. Given the emphasis on both resilience as a graduate attribute, but also on student mental health, there is a need for HEIs to provide strong messaging regarding what is meant by the term and how they believe it presents as an attribute of engineering graduates. It is also clear, especially the in light of the equality, diversity and inclusion (EDI) issues already present within engineering, that educators should understand and take on responsibility for providing an environment which allows all students to succeed.

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Rethinking Evolution of Active Learning in the Hybrid/Online Engineering Education in the Post-COVID-19 Era: A quantitative keyword co-occurrence analysis

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ABSTRACT

In response to COVID-19, education witnessed a rapid shift to online and virtual platforms. Our previous research has raised questions about the efficacy of these methods for hands-on practice and active learning experiences - crucial elements of engineering education. Emergent solutions like online laboratories and virtual field trips have led to the rise of a hybrid learning era in the post-pandemic context. This change necessitates a reassessment of active learning in hybrid/online engineering

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education. In this study, we examine recent literature on online and virtual education during and post-COVID-19 to redefine and reevaluate strategies for engaging students actively. We propose using VOSViewer to analyze the occurrence of keywords in post-COVID-19 literature to define a visualization between the interests in research and the content of key papers in situating active learning for hybrid/online education. We analyze the evolution of active learning theory, outline its characteristics in the new era, and propose a literature review focusing on how digital technology can synergize with learning approaches to foster active learning. We also address concerns related to hands-on practice and active learning and discuss innovations developed to mitigate these challenges. Our goal is to provide fresh insights and stimulate further research on enhancing active learning within hybrid/online engineering education in the post-pandemic era.

1 INTRODUCTION

With the World Health Organization declaring the end of the global COVID-19 emergency, engineering education has predominantly returned to on-campus settings. However, the three-year stint of online education during the pandemic has irrevocably changed the educational landscape, transitioning away from a strictly campus-centric learning environment (Gratchev and Espinosa 2022). Many institutions continue to offer a variety of online learning resources, fostering an environment where traditional campus and online/blended education coexist.

Our previous work, conducted at the onset of the pandemic, highlighted concerns regarding the development of social and practical skills in online engineering education due to the implementation of technological platforms as means for replacing communication platforms rather than as a learning tool (Piyatamrong et. al 2021). Solutions leveraging active learning strategies were proposed to address these concerns, such as virtual labs promoting constructivist thinking and active experimentation in online settings (Radhamani et al. 2021). Accompanying videos demonstrating procedures align with active learning strategies as they allow students to replicate processes autonomously by guiding their learning journey (Gratchev and Espinosa 2022). However, these studies were conducted during enforced quarantine, necessitating a reevaluation of active learning strategies within online/hybrid engineering education in the post-epidemic era.

This paper's objective is to revisit active learning in the context of online/hybrid education during and after the pandemic. We will discuss strategies to overcome the limitations of hands-on active learning and propose the concept of technology-mediated active learning. The paper unfolds in three stages. Initially, we will investigate the definition of active learning in engineering education, discussing its essence and the challenges COVID-19 has posed. Subsequently, we will analyze engineering education literature from the pandemic period to discern key strategies identified as facilitating active learning. Finally, we synthesize the findings, emphasizing the coexistence of hybrid/online and traditional engineering education in the post-pandemic era. We'll reconsider the definition of active learning and propose technology-mediated active learning as a promising opportunity for future developments in engineering education.

1.1 What is Active Learning in Engineering Education

Active learning has been defined as the "intelligently guided development of the inherent possibilities of everyday experience" (Christie and De Graaff 2017). Several methods of active learning exist, including project-based learning, flipped classrooms, and collaborative or cooperative work. Researchers have demonstrated the benefits of active learning in various types of engineering education through extensive literature reviews using diverse quantitative and practical methodologies (Lima, Andersson, and Saalman 2017). Hernández-de-Menéndez provides a comprehensive perspective on active learning in engineering education, describing it as an interactive, highly engaging, and student-centered approach that promotes learning through meaningful hands-on activities and critical thinking (Hernández-de-Menéndez et al. 2019). In this model, students are motivated to learn, the work is focused on learning objectives, and the instructor assumes the role of mentor and evaluator of progress.

While definitions may vary, most scholars concur that active learning implies student autonomy and promotes active cognitive engagement. Some researchers have narrowed the scope of active learning to classroom activities (Lombardi et al. 2021), conceptualizing it as either individual or group tasks that involve all students in class proceedings, wherein teachers process students' feedback and alternately provide novel information and instruction (Felder and Brent n.d.). On the other hand, Charles C. Bonwell has expanded the definition of active learning, categorizing any activity that provokes students to engage in reflection and critical thinking as active learning (Frost 1991).

Engineering education is highly structured and integrated, emphasizing the evaluation of project outcomes to gauge the understanding of course content and knowledge of diverse attributes. The teaching process also involves imparting abstract knowledge, such as engineering ethics and humanistic values. Given these characteristics, engineering education underscores the importance of independent study and scenario-based learning, thereby aligning closely with the tenets of active learning.

1.2 What Challenges COVID-19 Brings To Active Learning in Engineering Education

Our prior research (Piyatamrong et al. 2021) highlighted that the abrupt transition to online education at the onset of the COVID-19 pandemic was necessitated by the urgent need to ensure educational continuity. We observed that communication platforms such as Zoom and Microsoft Teams were swiftly repurposed as substitutes for in-person instruction. Yet, in the initial stages of the pandemic, these adaptations resulted in a loss of informal interactions between students and faculty, along with diminished opportunities for active learning and practical experience. In parallel, other studies, such as that by Seraj et al. (2022), reviewed pedagogical trends and assessment practices during the pandemic, capturing insights from both students and teachers. While several advantages of online learning were recognized—ranging from positive teacher-student experiences, and cost and time savings, to flexible and collaborative learning environments—concerns were also raised. These included issues related to academic support, learner autonomy, student-centered approaches, timely teacher responses, and the capability for ubiquitous learning in the online environment during the pandemic.

From a technological implementation standpoint, concerns were centered around the integration of courses with technology, internet connectivity, lack of interaction, technical infrastructure deficits, device unavailability, inadequate training, and motivational challenges. These findings, resonating with our research, suggest that the use of digital technology in online education presents notable challenges for active learning. We aim to further investigate the relationship between the realization of active learning and the application of digital technology in online education, drawing upon various scholarly publications.

2 METHODOLOGY

2.1 Research Design

This study employed keyword searches to identify pertinent literature sources for review. Given the narrow scope of this review and the specificity of the topic, the review's focus was to ascertain the relationship between active learning and technology-mediated education in online/hybrid engineering education during COVID-19. Therefore, a keyword search was utilized as an efficient strategy to promptly identify the most recent and relevant articles on this topic (Levy and J. Ellis 2006). Scopus was chosen as the database for this review due to its robust quality, diverse multidisciplinary journal coverage, and swift literature update frequency (Chadegani et al. 2013). From the database, 150 papers published between 2021 and 2023 were selected. The literature selection process was partitioned into three steps.

The first step centered on the identification of five keywords based on the review topics: COVID-19, learning and technology, technology-mediated education, engineering education, and active learning. Boolean operators were utilized in searches to include all potential keywords, thereby minimizing the risk of omitting critical papers. 'Online learning' and 'hybrid learning' were introduced as search keywords to generate a wider range of relevant papers. The inclusion of 'online learning' as the sixth keyword and the application of filters on the social science, engineering, and computer science subject categories yielded 225 results. When 'online learning' was replaced with 'hybrid learning', maintaining all other keywords and filters, 20 results were produced. In the second stage, the results from both searches were combined, and duplicates were removed, resulting in 230 relevant papers. The third stage involved a rigorous limitation of subject categories, excluding all articles unrelated to social science, engineering, and/or computer science. This led to a final selection of 150 articles. Considering that the keyword 'COVID-19' inherently signifies a specific time zone, all retrieved search results were published between 2021-2023, aligning with the review's temporal constraints. Consequently, all articles were deemed appropriate for inclusion.

2.2 Data Analysis

Keyword co-occurrence analysis is a robust method in bibliometrics, instrumental in evaluating the interconnected conceptual structure of research topics (Radhakrishnan et al. 2017). Therefore, this study utilizes VOSviewer (Van Eck and Waltman 2010) for a quantitative keyword co-occurrence analysis. The software's sophisticated algorithm identifies clusters of keywords, represented by distinct colors, and calibrates the interrelationships among these keywords. The software-generated map exhibits these connections through label sizes, keyword nodes, and lines connecting these nodes. The frequency of keywords can suggest the popularity of a particular topic. Furthermore, the clusters depict which keywords are frequently associated, while the connecting lines illustrate the strength and nature of these relationships (Van Eck and Waltman 2014).

From the 150 references selected for this study, 839 keywords were extracted. Initially, a minimum co-occurrence rate of 3 was set for the keywords, of which 66 satisfied this criterion. The second stage entailed a manual screening process to eliminate words with overlapping meanings (e.g., 'covid-19 pandemic', 'pandemic') as well as words deemed irrelevant or overly general (e.g., 'teacher', 'student', 'learning'). Lastly, total link strength attributes demonstrate the total strength of an item's links with other items (van Eck and Waltman, n.d.). Keywords with a total link strength of less than 6 were eliminated, as this insufficient connection strength suggested the keyword's lack of relevance to others. The remaining 36 keywords were deemed significant and were subsequently utilized for analysis.

3 RESULTS

3.1 Finding

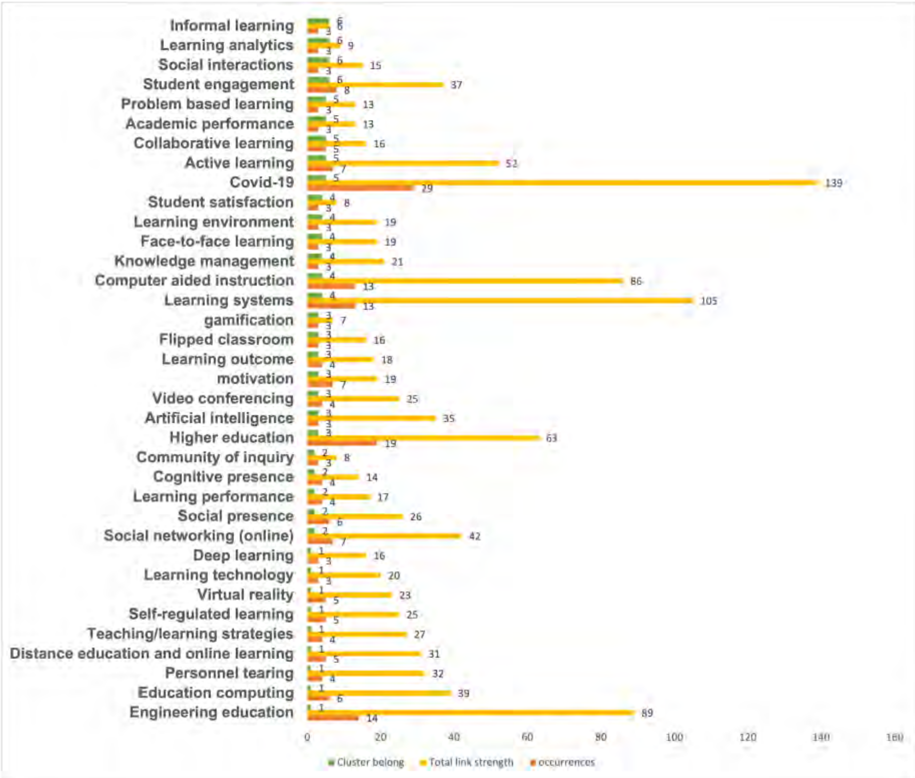

Fig. 1. Co-ocurrency analysis and cluster classification

Figure 1 presents the analyzed keywords, their occurrence frequency, and their total link strength along with the cluster classification. The table reveals six keyword clusters, each containing a comparable number of keywords. This suggests that the six research categories connected with this topic carry equivalent significance. Clusters 1, 3, and 5 represent novel technologies in hybrid/online engineering education pertinent to practical skills during the pandemic, such as educational computing, virtual reality, artificial intelligence, video conferencing, and gamification. These emerging technologies are integrated into traditional active learning strategies like the flipped classroom, self-regulated learning, deep learning, motivation, collaborative learning, and problem-based learning.

Cluster 2 elucidates concerns in hybrid/online engineering education related to social networking (online) and social presence, alongside some active learning-related solutions such as cognitive presence and the community of inquiry. Cluster 4 illustrates the aspects of active learning in engineering education that have been affected by COVID-19, encompassing learning systems, learning environment, and student satisfaction. Lastly, Cluster 6 describes the specific attributes of active learning in hybrid/online engineering education during the pandemic, focusing on student engagement and informal learning.

When sorted in descending order based on total link strength, and excluding keywords used in the literature search, the most prominent keywords are learning systems, computer-aided instruction, higher education, social networking (online), education computing, student engagement, artificial intelligence, personnel training, social presence, self-regulated learning, video conferencing, and virtual reality. The most researched themes in active learning in hybrid/online engineering education during the pandemic, incorporating these keywords, are social skills concerns, technology strategies for practical skills, and the characteristics of active learning.

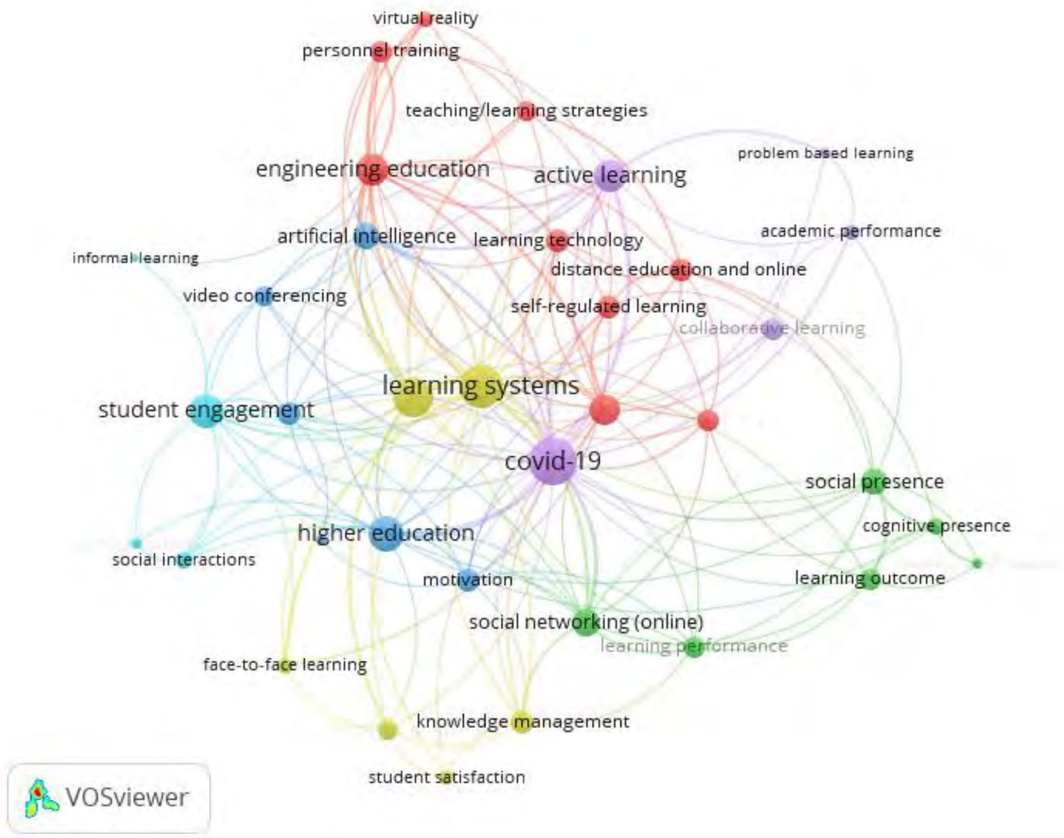

Fig. 2. Keywords mapping

The keyword connection map is depicted in Figure 2, where the colors represent various word clusters, the size of the label represents the number of other keywords linked by the word, and the lines represent the keyword connections. As illustrated in the figure, keywords with numerous connections to other keywords span across different word clusters. These prominently interlinked keywords include COVID-19, active learning, learning systems, computer-aided instruction, student engagement, and engineering education. Moreover, all word clusters contain multiple keywords linked to other clusters, corroborating the potent relationship between hybrid/online engineering education, active learning, and technology.

Through the combined analysis of word clusters and keyword link strength in Figure 1, along with the visual representation of interconnections in Figure 2, it can be inferred that in the research conducted during the pandemic, social skills and practical skills emerged as paramount challenges for active learning in hybrid/online engineering education. Further, novel technical strategies, such as virtual reality, artificial intelligence, and video conferencing, have been proposed due to their alignment with active learning principles. These strategies are anticipated to tackle the issues associated with social and practical skills.

3.2 Discussion

In the post-pandemic era, hybrid/online engineering education will exist alongside traditional engineering education, thereby transforming the landscape of campus-based engineering education. Our study highlights the increased usage of innovative technologies, including Web technologies, virtual laboratories, and virtual reality to foster active learning, both from the standpoints of student learning and pedagogical methodologies. The technological advancements utilized during the pandemic have offered fresh insights into the future direction of active learning.

In our search of keywords among various literature discussing the proposed topics, we see centroids of keywords surrounding learning systems, learning technology, and student engagement as a central bridge between clusters of other keywords. This suggests the need to explore the literature on digital tools promoting learning systems, learning technology, and student engagement to critically think about how the tools can promote active learning and what challenges they could bring to hybrid/online engineering education.

It is apparent from this study, and the literature, that a range of digital tools have emerged that can support active learning within the context of online engineering education. Foremost among these are interactive simulations and virtual labs, which have been found to be as effective as physical labs in promoting learning outcomes (Ma and Nickerson 2006). These tools allow students to manipulate variables, conduct tests, and observe results in real-time, thereby providing a hands-on experience within a virtual environment. Moreover, the principles of gamification can also be incorporated to enhance the interactivity and engagement of online learning. By integrating game-based elements, the learning process becomes more immersive, thereby fostering active participation, increasing motivation, and improving knowledge retention (Huang and Soman 2013). The technologies of Augmented Reality (AR) and Virtual Reality (VR) further extend these interactive capabilities. In engineering education, AR can be utilized to visualize complex structures, while VR can enable students to practice skills within a safe, simulated environment (Radianti et al. 2020).

However, the feasibility of implementing such advanced tools in every class session could be challenging, hence, to explore the promotion of active learning for engineering education in hybrid/online learning, we suggest various approaches to enhance student engagement and create a learning system. Discussion boards and forums, for example, can facilitate active learning by encouraging students to engage in intellectual discourse, debate concepts, and pose inquiries. Platforms like these can also facilitate peer feedback, a key element in the learning process (Garrison, Anderson, and Archer 2000). Adaptive learning platforms have also shown promise, using algorithms to tailor the learning experience to each student's needs, thereby offering personalized feedback and resources. This approach ensures the material is appropriately challenging, promoting active learning without overwhelming students.

Collaborative tools, such as Microsoft Teams (Romadhona and Dwiningsih 2021), can further enhance this experience by enabling group projects or brainstorming sessions and fostering critical thinking skills (Johnson, Johnson, and Stanne 2006). The responsibilities for promoting student interactions and the effectiveness of active learning systems through discussion boards, forums, and adaptive learning platforms will depend greatly on the skills and encouragement of the lecturers. This, therefore, emphasizes the need for greater technological and pedagogic support for lecturers in designing and running blended and hybrid course modules based on active learning.

4 CONCLUSION

The paper contributes a new quantitative literature analysis perspective that reflects the growth of active learning in blended/online engineering education in the post-pandemic era. However, the research methodology is not without limitations. For instance, the use of a single database and keyword search may result in the omission of relevant literature, leaving space for improvement in future research. In conclusion, the use of technology in online engineering education introduces a variety of strategies for active learning, each with its distinct advantages and challenges. As we navigate the post-COVID-19 landscape, the careful selection and application of these methods become crucial in fostering active learning and enhancing the quality of education. The responsibility increasingly falls on educators to rethink the interactions between students and teachers, and among students themselves, as well as to redesign pedagogical approaches. The goal is to shift from considering digital tools as simple communication platforms to recognizing them as platforms for implementing integrated learning systems. By doing this, we can fully harness their potential to achieve active learning objectives, thereby bringing about significant change in the field of education.

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Feature Model Construction of Learning Factories Based on Authentic Learning Theory: A Case Study of the School of Micro-Nano Electronics at Zhejiang University

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ABSTRACT

The learning factory is an educational environment that simulates real-world production systems to bridge the gap between theoretical knowledge gained from academic settings and practical skills required by businesses. To improve

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the construction of learning factories at the early stage, a case study of the School of Micro-Nano Electronics at Zhejiang University has been conducted. First, an analysis framework based on authentic learning theory was developed to determine the critical elements of a learning factory based on four dimensions, including context authenticity, task authenticity, individual authenticity, and impact authenticity. Second, taking the School of Micro-Nano Electronics at Zhejiang University as the research object, qualitative analysis is utilized to further identify the essential elements of the construction model of learning factories. Additionally, an overemphasis on physical settings and a lack of industrial involvement have been identified. It suggests that it is essential to focus on effective industry engagement and strike a balance between the construction of the physical environment and the learning process. The findings provide construction insights for learning factories in their early stages of development.

1 INTRODUCTION

Over the past decade, concerns have emerged about engineering graduates lacking a comprehensive understanding of practical experience with real engineering sites and soft skills such as problem-solving, innovation, and management (Tell and Hoveskog, 2022). Hirudayaraj et al.(2021) reported that employers expressed deep concerns about the preparation of college graduates and revealed a great disconnect between what employers expect and the level of higher education considered as prepared for work. Thus, a significant emphasis has been placed on integrating practical experiences and real-world applications into engineering education. Several representative reports have been published, including *A Focus on Change, Engineering Education: Designing an Adaptive System, and The Engineer of 2020: Visions of Engineering in the New Century*, that urge engineers to return to the practice of engineering. This trend has led to the development of a new engineering education model based on learning factories, which have become more widely applied. Learning factories are highly authentic learning environments in which genuine products are manufactured in a simulated but life-like production setting. Following an action-oriented learning event within the Learning Factory, students may perform better in applications and develop more action-substantiating knowledge than after receiving conventional instruction (Cachay 2012; Rentzos et al. 2014). Since the learning factory has only been operating for a short period of time in China, the mechanism has yet to be perfected. How do learning scenarios simulate real-life industrial sites? What challenges do Chinese learning factories face during their early stages? Are still unclear. To improve the construction of learning factories in the early stages, a case study of the School of Micro-Nano Electronics at Zhejiang University will be conducted in this study.

2 LITERATURE REVIEW

2.1 Learning Factories

Learning factories are educational environments that simulate real production systems, allowing students to perform, evaluate, and reflect on their actions in an on-site learning approach (Wagner et al. 2012; Abele et al. 2015). These learning experiences aim to bridge the gap between the theoretical knowledge gained from academic settings and the practical skills necessary for the workplace (Bender et al. 2015).
In a literature review on learning factories, we typically find studies that explore the following areas. **(1) Definition and concept of learning factories.** The literature discusses learning factories' definitions and core concepts, highlighting their purpose, objectives, and critical features (Abele et al. 2017). They also investigate how learning factories differ from traditional educational approaches and how they enhance students' practical skills and industry readiness (Hamid et al. 2014) **(2) Pedagogical approaches and instructional methods.** Studies explore the pedagogical approaches and instructional methods employed in learning factories, including project-based learning, problem-based learning, experiential learning, and collaborative learning strategies (Bender et al. 2015). Researchers also investigate the effectiveness of these approaches in promoting active engagement, critical thinking, and interdisciplinary and soft skills development among students (Tisch et al. 2013). **(3) Facility design and technology integration.** Learning factories for production process improvement have been raised with lean methods and principles, like value stream analysis and design, just-in-time, line balancing, problem-solving, or job optimization (Abele et al. 2015). They also examine the role of modern manufacturing equipment, simulation tools, virtual reality, and data analytics in enhancing the learning experience and replicating real-world industrial environments (Kreimeier et al. 2022). **(4) Best practices and case studies.** A large amount of literature is case studies of different learning factories worldwide, for example, PTW at TU Darmstadt, the Learning and Innovation Factory (LIF) for Integrative Production Education at Vienna University of Technology (Erol et al. 2016), and the LPS Learning Factory at Ruhr University (Pittich et al. 2020). These examples highlight effective strategies, innovative approaches, and lessons learned from the establishment and operation of learning factories (Baena et al. 2017).

Overall, the majority of the literature primarily focuses on the experience summary of mature learning factory operational models in Western countries. On the one hand, it lacks a structured and scientific analytical framework, resulting in a lack of systematic analysis. On the other hand, little attention has been given to the challenges faced by learning factories during the early stages. Thus, we try to refine the construction model of learning factories structurally based on authentic learning theory. Furthermore, analyze the challenges learning factories face during their initial development phases.

2.2 Authentic learning framework

Authentic learning describes a pedagogical approach in which learning tasks are embedded within a real-world context. It offers students the opportunity to experience the same problem-solving challenges they face daily in the curriculum, allowing them to improve their problem-solving skills (Herrington 2014). It is an essential component of learning factories as it emphasizes the application of knowledge in real-world contexts. In a learning factory, students have the opportunity to work on authentic tasks and projects that simulate real-world manufacturing or production processes. By working on authentic tasks, students develop a deeper understanding of the subject matter, acquire practical skills, and apply their theoretical knowledge in a practical setting.

In order to explore the construction mode of learning factories in a more structured manner, it is necessary to bring in the analytical framework of authentic learning theory. This study mainly draws upon the authentic learning framework developed by Strobel et al. (2013). As shown in Table 1, it includes four dimensions, contextual authenticity, task authenticity, personal authenticity, and impact authenticity. Contextual authenticity refers to the resemblance between learning and real-world contexts. Task authenticity focuses on constructivist-type learning tasks in which students may be challenged to make decisions in practical contexts. Personal authenticity includes actions that make an experience authentic on a personal level, such as self-exploration. Impact authenticity pertains to the effective application of students' learning outcomes or activity products in real engineering contexts beyond school. These four dimensions of authenticity are conceptualized as bringing the learner closer to the realities of the workplace.

3 METHODOLOGY

This study adopts a mixed-methods approach, combining primary and secondary data about the School of Micro-Nano Electronics at Zhejiang University. The School of Micro-Nano Electronics at Zhejiang University is a prestigious academic institution in China dedicated to research, education, and innovation in micro-nano electronics. It began operating its *CMOS integrated circuit chip design and manufacturing innovation platform* in 2022. The platform provides a complete process innovation environment that includes chip design, fabrication, testing, and characterization. Also, it provides advanced facilities and resources for research, including computer-aided design (CAD) tools, simulation software, cleanrooms for fabrication, testing, and measurement equipment, and a team of experienced researchers and engineers. This platform allows students to explore and advance the field of CMOS integrated circuit chip design and manufacture.

Primary data are collected primarily through telephone or e-mail interviews with teachers and students with experience on the platform. Secondary data are collected from sources such as the college's official website, news reports, and databases such as CNKI. Once all surveys were finished, the researchers organized the codes into groups and constructed themes by describing the relationship between the grouped codes. A total of 252 items were included in the final corpus of studies.

Table 1. Coding Results

Code	Definition	N	%
Context authenticity	What makes a context is or resembles a professional context?	94	37.3%
Task authenticity	What makes activities resemble real-world activities?	42	16.7%
Personal authenticity	What makes experiences authentic on a personal level?	25	9.9%
Impact authenticity	What impacts can authentic experiences deliver?	91	36.1%

4 RESULTS

Through the analysis, we identified four important themes, including **(1) Context authenticity, (2) Task authenticity, (3) Personal authenticity,** and **(4) Impact authenticity**. In the following section, we will describe each of them. As a reminder, when participants' quotes are used, they are italicized, and themes appear in bold italics.

4.1 Context authenticity

Learning factories are designed to provide practice contexts that closely resemble real-world settings. This theme constitutes 94 of the 252 items, which is the largest category. In order to meet learners' practice needs, a focus on context authenticity is placed on both a production context and an interactive context. **(1) Real production context.** The real production context is represented by 38 items, which indicates a strong focus on the physical layout of the facilities to support the intended operations. An assembly line equipped with equipment, machinery, and software similar to or identical to the real-production settings has been adopted. Such as 3D printers, robotics systems, and data analytics tools. Students learned how to operate and optimize their use, as physical objects can provide engagement. Participant 1-3 said, *" Cutting-edge equipment, such as photolithography machines, helped us become familiar with the tools used in our future careers."* Additionally, factors such as available space, safety protocols, and ergonomics should be considered to ensure the facility is conducive to simulations of real-world manufacturing scenarios. **(2) Real interaction context.** 56 items are included about the real interactive context. Learning factories engage with universities, industries, and the government to establish partnerships for resource support, joint projects, and knowledge exchange. Interactions with the government account for the most with 40 items, which reflects the top-down characteristics of the learning factory construction in China. Governments provide overall direction, allocate resources, and monitor learning factories' performance. As participant 6-4 expressed, *"It was initially funded by governments, including infrastructure grants by governments of Zhejiang Province, Hangzhou City, Xiaoshan District, and Zhejiang University. "* Surprisingly, enterprises show little interest in learning factories as industry involvement provides valuable insights, mentorship opportunities, and exposure to real-world challenges. This construct has yet to be included in many of the most widely cited examples of learning factories in other countries.

4.2 Task authenticity

Task authenticity ranked third with 42 items. Moreover, the majority referred to Practices of full product life cycle with 25 items, followed by Real Problem-based with 10 items, and Follow Manufacturing Standards with 7 items. **(1) Real Problem-based**. In contrast to simulated or theoretical exercises, the learning factory provides an environment where students can solve real-world problems encountered in industrial settings. A real problem can be presented in various ways, for example, as a topic for competitions, a project to be contracted out to schools, or as a case study. Real problems can be complex, dynamic, and ambiguous and need to be solved within a tight budget and limited time. By engaging with real problems in a controlled learning environment, students gain first-hand experience tackling complex issues and developing practical solutions. According to participant 4-5, "*the program provides students with the opportunity to confront industry-specific challenges directly and improves their ability to think critically and solve problems continuously."* **(2) Practices of full product life cycle.** Instead of being pure technical demonstrators, learning factories serve as venues for students to participate at all stages of a product's life. It includes product development, production, distribution, marketing, and use. The majority of the items focused on the production stage. This stage emphasizes efficiency, quality assurance, and meeting production targets, with 16 items. Students gain hands-on experience using manufacturing equipment, interpreting data, conducting experiments, and implementing solutions. By incorporating practices related to the full product life cycle, learning factories provide students with a holistic perspective on product development and management. Participants 12-2 commented, *"We gain a deeper understanding and experience of integrated circuit design and manufacturing processes."* **(3) Follow manufacturing standards.** Manufacturing standards are followed to ensure consistent quality, safety, and efficiency. Also, by aligning with standards, students develop critical attributes such as attention to detail, precision, and protocol adherence. It prepares them for a smooth transition into professional roles. Participant 3-5 stated, *"The 55nm process chip has a width of no more than 0.946mm and a length of no more than 1.96mm. "*

4.3 Personal authenticity

Personal authenticity takes up a tiny proportion, with only 25 specific items. There are 11 items related to Enhancing Students' Subjectivity and 14 items related to Transforming Teachers' Roles. **(1) Enhance Students' Subjectivity**. Rather than learning through interaction with a single perspective (the teacher's), students are encouraged to take ownership of their learning, set goals, and make decisions regarding their projects and activities. They are also encouraged to articulate, negotiate, and defend their growing understanding through peer and teacher interactions. Participant 22-9 said, *" This activity aims to showcase students' outstanding performance and encourage academic exchange, enabling students to share their research freely."* Furthermore, a more significant proportion of elective courses have been provided in the curriculum to encourage personalized learning based on the capabilities of each student. Students are able to develop a sense of autonomy and agency through the enhancement of their subjectivity, which is essential for their personal and professional development. **(2) Transform the teacher's role.** The teacher's role has evolved from a traditional instructor to a scaffolder in the learning factory. Participant 10-2 introduced that *"Teachers adopt interactive teaching methods such as peer teaching, discussion sessions, and flipped classrooms."* While teachers can still play a crucial role in supporting students' learning, providing guidance, and sharing their practical knowledge and expertise, the critical difference is that students determine when and how the support is delivered. The scaffolding is gradually removed once the child can perform the tasks on his or her own.

4.4 Impact authenticity

Impact authenticity ranked second with 91 items. The most critical items were human capital development with 49 items, followed by Knowledge production with 31 items, and Generating economic benefits with 11 items. **(1) Human Capital Development.** First, practical learning experiences enable students to develop technical skills directly transferable to industry settings. Second, learning factories foster a collaborative environment where students from different disciplines work together on interdisciplinary projects. This collaboration promotes teamwork, effective communication, and cross-disciplinary work. Third, learning factories promote a growth mindset, encouraging students to embrace lifelong learning and adapt to changing industry dynamics. By developing these skills, students are enhanced in their employability and prepared for a smooth transition into the workplace. As Participant 4-9 said that *"The employment rate in 2021 was 100%, with graduates being employed in top-tier companies such as Texas Instruments, Cisco, and Huawei. "* **(2)Knowledge production.** Learning factories provide a platform for industry-driven innovation. Learning factories provide a platform for industry-driven innovation. Researchers and students can collaborate on industry challenges and develop practical solutions, where academic knowledge and research can be applied to develop new technologies. For example, Participant 8-2 said: *"Learning factories attract corporate participation in joint research and development. Therefore, duplicate R&D investments are reduced, and 1.5-2 years are saved in the process of* *launching a new product. "* In addition, learning factories encourage interdisciplinary collaborations, leading to the generation of new insights. For example, Participant 10-2 said: *"We actively collaborate across disciplines, exploring the fundamental and common vital issues constraining the future development of technology and industry.* **(3)Generate economic benefits.** Students and researchers have the opportunity to explore creative ideas, develop prototypes, test innovative solutions, and generate valuable knowledge and intellectual property in learning factories. Research and innovation can lead to the development of new products, processes, and technologies, fostering economic growth and competitiveness. Participant 18-2's statement exemplifies:*" The learning factory serves as a test bed for hardware and software partners from the industry and as a demonstration facility for ongoing research projects. "* Also, by fostering an entrepreneurial mindset and providing access to entrepreneurial ecosystems, learning factories contribute to the creation of new enterprises and job opportunities, promoting economic growth and fostering a culture of innovation.

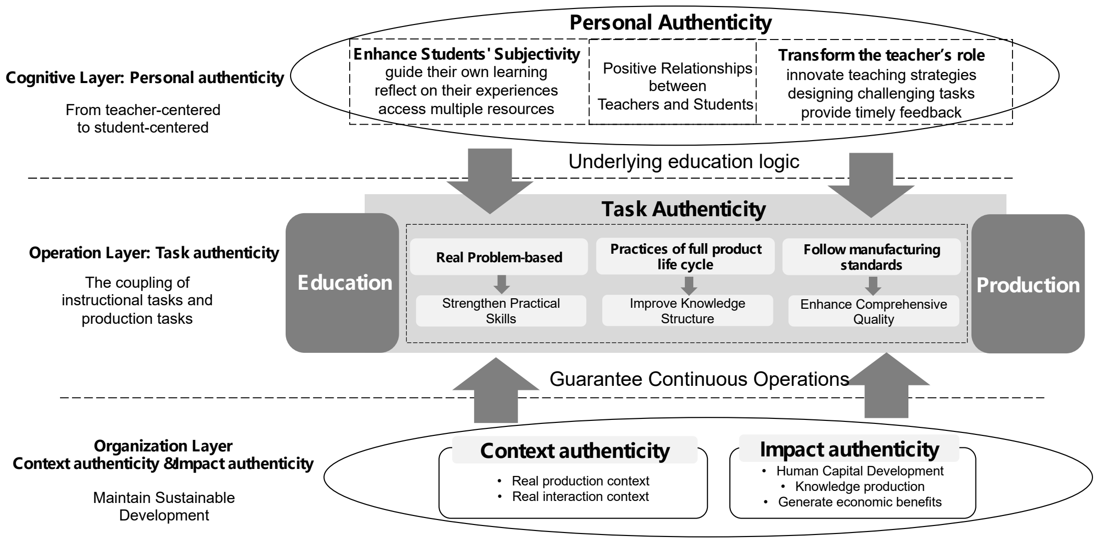

Fig. 1. Feature Model Construction of Learning Factories

5. DISCUSSION

As learning factories are relatively new and evolving in China, some common mistakes that have been observed are as follows.

First, a learning factory is not simply intended to demonstrate a simple copy of a production factory but an optimized learning process designed to foster the participants' ability to self-organize and act within authentic learning environments. However, some institutions mistakenly believe that merely creating a well-equipped physical space will automatically lead to effective learning experiences. Also, the desire to attract attention or funding may drive the emphasis on tangible and easily measurable elements such as machinery, technology, and workstations. However, physical settings are often prioritized in learning factories at the expense of pedagogical approaches, teacher

training, and curriculum development. A lack of engagement and involvement in the learning process may result from this imbalance, leading to a superficial learning experience. To mitigate these negative effects, learning factories need to strike a balance between the physical environment and the learning process. It involves developing learner-centered approaches, focusing on pedagogical innovation, and aligning the learning process with the physical environment. A strong emphasis should be placed on active learning methods, problem-based learning, and real-world projects that engage the students and encourage critical thinking, creativity, and teamwork.
Second, there needs to be more industrial interaction and economic benefits associated with learning factories in China. The pure operation of a learning factory focused on providing a hands-on learning environment for students may not be economically sustainable due to significant investments in equipment, facilities, and personnel. Furthermore, a lack of engagement from enterprises may prevent students from being exposed to the latest industry requirements, trends, and technologies. There could be several reasons why learning factories in China lack engagement from enterprises. First, enterprises may perceive learning factories as primarily focused on educational purposes rather than directly benefiting their business operations. They may view them as separate from their core activities and not see a clear link between participation in learning factories and achieving their business objectives. Moreover, some small and medium-sized businesses may lack the financial resources, personnel, and infrastructure to engage actively in learning factories. For the purpose of not only building up but also continuously operating. It is important to ensure that industry partners are actively involved in designing and operating learning factories. It can be achieved through effective communication, showcasing successful case studies, demonstrating the practical benefits to enterprises, and fostering partnerships and collaborations between academia and industry.

6. CONCLUSION

The learning factory is an innovative educational approach that integrates theory and practice by simulating real-world manufacturing environments. It provides students with hands-on learning experiences and practical training in production, process optimization, and problem-solving. In this study, we are interested in the feature model construction of learning factories. A framework based on authentic learning theory was developed based on four dimensions: context authenticity, task authenticity, individual authenticity, and impact authenticity. Additionally, we used qualitative analysis to identify the essential elements of the learning factory model at the School of Micro-Nano Electronics at Zhejiang University. And an overemphasis on physical settings and a lack of industrial involvement have been identified.

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Practice Papers

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IMPROVING COMMUNICATION PROCEDURES BY MEANS OF VIDEO-RECORDED PROPOSALS

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ABSTRACT

There is an agreement regarding the importance of communication in the promotion processes of all types of technical or entrepreneurial initiatives. Communication skills have to make it possible to obtain the maximum interaction with the agents involved and facilitate the commitment of these agents to a project. In this context, communicators' erroneous perception of their own abilities and of how they are transmitting the information is a significant drawback that calls for improvement. Video-recording someone when speaking creates an impact on them given that the possibility of seeing themselves implies a significant change in the learning process. This technique has been applied as part of the teaching activities in the energy engineering master at the Universitat Politècnica de Catalunya and InnoEnergy.
In the experience developed, the students follow a first block in which they analyse a technological opportunity and subsequently detail a proposal to develop this opportunity. They prepare an oral presentation to deliver their proposal. This presentation is video-recorded and is the starting point of a second block of the course. In this block, some concepts and guidelines on communication are presented. Finally, a new proposal presentation based on the analysis and improvement of the previous presentation carried out is delivered. We conclude that these procedures can lay the ground for novel guidelines in the area of communication skills for technological innovation projects promotion.

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INTRODUCTION

Innovative teaching practices, such as project-based teaching (Beckett & Slater, 2020), have become frequent in the context of engineering in Higher Education. Communication has been considered one of the main skills needed in engineering and the lack of focus in it one of the main deficiencies in engineering education (Crawley et al., 2007). At the same time, necessary skills for the professional of the twenty-first century include creativity, curiosity, critical thinking, entrepreneurship, collaboration, communication or global competence (Zhao & Watterstone, 2021), bringing to the fore the existing relationship between entrepreneurship and communication competencies, and hinting at the need to take on a holistic stance to disciplinary literacies such that these skills are contemplated in higher education (Heron et al., 2021).

In many European technical universities, engineering students are sometimes assumed to come to class already equipped with these skills in their mother tongue and often English in the case of English Medium Instruction (EMI), as evidenced in the insufficient presence of languages for specific purposes courses in curricula. Considering that not only L2 speakers of English but also speakers in their mother tongue need to learn complex speaking skills (Dippold et al.,2019), such as persuading and negotiating, the assumption that engineering students have acquired them before reaching university may be unsupported and particularly unfair for students whose socioeconomic background could not provide them with sufficient resources and opportunities.

The need for a specific teaching of communication skills (Leung & Lewkowicz, 2013) for engineering as part of the necessary academic literacies that meet the specific needs of the current generation of engineering students proves essential in a course tackling entrepreneurship or technological innovation. Communication being a central activity of engineering professionals, having a good command (in English and in their first language) of the technical and formal register, of the most frequent documents, and of the common communicative situations they find themselves at work seems very pertinent in a globalised labour market (Heron et al., 2023) where engineers have to communicate effectively and appropriately to a highly diverse range of stakeholders.

Thus, communication should play an outstandingly vital part when the course is on entrepreneurship, given that obtaining the maximum interaction with the agents involved and facilitating the commitment of these agents to a project can determine its successful implementation. In a project-based engineering course on entrepreneurship, like the one under study, the project is usually viewed from a process perspective, the process involved in guiding students toward the processes that are required in all types of technical or entrepreneurial initiatives. One such promotion process is oracy, i.e. oral communication skills, which in the case of an entrepreneurial project implies orally communicating the project both to in-company and external audiences and for both informative and persuasive purposes. Surprisingly enough, in research oracy seems to be framed as a product explored through monologic activities and evaluated through summative assessment (Heron et al., 2021) or from the digital communication skills standpoint (Bobkina and Dominguez Romero, 2022). Thus, the departure point of this study is not only the need to include academic oracy as one of the entrepreneurship skills but also the need to frame these oral communication skills along the same lines of the process perspective underlying a project-based course. Our project-based entrepreneurship course is based on a student-centred, inquiry-based, authentic and purposeful activity that requires students to explore solutions to authentic and significant problems by means of creativity, critical thinking skills and entrepreneurial spirit to be able to finally present an entrepreneurship proposal. Apart from this, students also develop abilities to cope with the unknown and uncertainty. Instead of requiring memorization of known solutions to known problems, students develop their learner autonomy–understood as the capacity to take responsibility for one's own learning (Brown, 2005; Benson, 2013). Because this pedagogy places the student at the centre, it seems reasonable to include self-assessment as part of this learning process where students take an active role, thus going beyond the view of feedback as mere transmission, a product.

It is against this backdrop that we seek to analyse the impact of self-assessment when students take on a metacognitive stance and are asked to watch their performance in a video-recorded team presentation of their entrepreneurship project. The main research question we address is: Is video recording student presentations a useful tool to obtain self-awareness about one's communicative shortcomings and foster the learning process?

1 METHODOLOGY

1.1 Context and Participants

As mentioned above, we analyse engineering students following a project-based course on entrepreneurship and technological innovation. The course was taught by the two authors during the spring semester of the academic year 2022-23. The activity described in this article is part of the teaching activities in the field of energy engineering at the Universitat Politècnica de Catalunya and InnoEnergy master school (Olivella et al. 2018). The course consists of two blocks; the first deals with technical entrepreneurship and innovation and is taught by a lecturer from the industrial engineering department; the second and shorter one is on communicating the entrepreneurship project they have developed in the first block and it is taught by a lecturer specialised in English for Specific Purposes and technical communication. When the first block is over and just before the second block starts, students orally present their project in front of their classmates. This first mock presentation, which is not graded, is video-recorded and sent to every team so that students watch and assess themselves, reflecting on their performance in an assignment. In subsequent classes the communication lecturer gives them personalised feedback and devotes several lessons to cover key communication aspects and skills–encapsulating both verbal and non-verbal behaviour– to be both informative and persuasive and addressing different audiences and situations. On the last day, every team delivers their presentation in front of both lecturers, who this time will assess and grade students' performance in terms of content and communication. This tandem teaching thus allows teachers to integrate language and content in a realistic way, as for an innovative project to become a reality and succeed, both the solution proposed (content) and how efficiently it is delivered (oral communication), have to be professional and up to the standard.

Both groups were taught through the medium of English (EMI) and comprise a high percentage of Erasmus students in class. Out of the 36 students enrolled, 30 gave the presentation and were video- recorded. As already mentioned, students were asked to answer a short reflection questionnaire as a class assignment after viewing their first performance. Twenty-eight (out of 36) students completed the reflection assignment. As the questions in this reflection questionnaire were open and students had a lot of space to write, students' answers were rather long and varied. The answers were thematically analysed, after coding was carried out (examples of codes were: eye contact, voice, intonation, preparation, memorising, key words, etc.). This coding allowed us to obtain several recurrent themes (i.e. Content Planning versus Delivery and Verbal versus Non-verbal communication).

1.2 Instruments

The written reflection questionnaire after having watched the presentation comprised seven questions:

1-As a group presentation, what is your assessment?

Individual assessment:

3-What do you think of your presentation and how satisfied are you with your performance?

4-What are your strengths? Briefly explain.

5-What are your weaknesses? Briefly explain.

6-Of the weaknesses you have outlined, which one is for you the most difficult to overcome and why?

7-Is there any topic or content that you would like to cover in this course as regards persuasive oral presentations? Suggestions are welcome.

2 RESULTS

2.1 Findings of the reflection questionnaire

Findings of the reflection questionnaire were thematically analysed. The analysis of the first question (*as a group presentation, what is your assessment?)* revealed students' overall satisfaction (21 mentions), although after assessing their team favourably (t*he presentation went well, it was fluid and complete*), they all highlight there is room for improvement. While some students give very general information (*communication part could have been better*), others are noticeably articulate, as shown in the representative excerpt below:

> *First, I think it is better not to have notes while giving a presentation, no matter if they are on a paper or on a phone. We should not have brought any of them, this way we could have all use our hands to point things on the slide show but also have our eyes looking on the person we are talking to. Secondly, I think that our presentation may have lack of energy. The tone overall employed was quite the same during the 10-minute-speech, but it should be more energic to convince better the people we are selling our technology to. We could have had transitions to our slide show, but also taken a more energetic position, using more our hands to show things, or putting more interactions in our presentation. (*Student 9)

In the second question enquiring into their individual performance (*how satisfied are you of your performance?*), all students but three reported being quite satisfied with their performance. When elaborating on their self-assessment, some of them mentioned only issues related to content and Planning, in both negative and positive ways (e.g. *good technical specifications; lack of structure; we showed our knowledge; well summarised and easy to understand; the slides are easy to read and with the right amount of information; design of the slides could have been better; I wish I would have come more prepared*). Most comments, though, pointed to the Delivery itself, more specifically to body language (intonation, pace, eye contact, too much/little body movement, and anxiety (e.g. *my nervousness made my voice shaky and less confident. I could have kept my posture for a more formal appearance-* Student 24).

Worth mentioning is the always negative assessment regarding their lack of confidence, fluency, showmanship and dynamism, as illustrated in the two excerpts below:

> *- I am more disappointed with my attitude during the passages where I do not present because I have a really fixed look and I am too relaxed. I need to work on that and also work on hiding some of the tics I've noticed from the recording* (Student 19)
> *-improving our narrative and being more convincing* (Student 25)

The third question eliciting their perceived *strengths* also yields a variegated range of answers, which were classified according to Planning the content and the Delivery itself. In terms of content, their acquired expertise and knowledge seems to be conducive to confidence: *the confidence in the information. I was confident due to the investigation we did before the presentation* (Student 26), while others refer to the preparation of the slides (*I can make slides that are not too heavy: I put key* *words on the slides, and complement the slide with words. I think this helps the audience to recognize what is the most important part of my speech*- Student 14*)*. The overwhelming majority of comments stress aspects related to the Delivery (English *is understandable, clear; being fluid and acquainted with the English language and colloquialisms; clear voice; arms and hand gestures*). A few students mentioned being good at memorising and only two students, who reported having done theatre and received prior training in public speaking, mentioned their lack of anxiety. One student replied having no strength at all.

As to the *weaknesses* identified, students again place more emphasis on the Delivery (verbal and non-verbal behaviour) than on the Planning and rehearsing aspects. The students wrote lengthy answers here, which are summarised in Table 1 below:

Table 1. Weaknesses identified (students could mention more than one at a time).

PLANNING & REHEARSAL	DELIVERY: VERBAL	DELIVERY NON-VERBAL
insufficient practice and rehearsal 4 mentions	abuse of fillers ('uhm') 10 mentions	lack of eye contact (dependence on notes or screen) 8 mentions
lack of preparation (lack or organisation of talk and slides) 4 mentions	English level, accent, pronunciation (not my mother tongue) 7 mentions	Speaking too fast, no pauses 6 mentions
skipping too much of important information	repetition of the same word 3 mentions	Body language (fidgety, no gestures or excessive gestures/ movement) 5 mentions
Not making greater use of the visual support when speaking 2 mentions	more fluent, less hesitant, and engaging with audience 3 mentions	anxiety, being nervous 4 mentions
Too reliant on memory 2 mentions	Boring, not energetic 2 mentions	What to do when not speaking 3 mentions

The *most difficult weakness to overcome* for them (question 6) can be attributed to nervousness and anxiety. Students seem to have gained significant awareness about the underlying cause of many of their weaknesses: they think that as a result of feeling nervous, they make the following two mistakes: a) use too many fillers (*the "uhm". It is a subconscious mechanism to avoid silences in the presentation and as so it is difficult to overcome* -Student 26); b) maintaining eye contact (*looking too much at the presentation, it is not because I don't remember the information, it is to avoid eye contact with the audience. It makes me nervous to look on the eyes of people superior than me* -Student 11*).* In short, fear of speaking in public seems to be at the root of the problem, albeit the presence of the camera exacerbates stage fright.

Worth mentioning is the bulk of replies in the last question *(Is there any topic or content that you would like to cover in this course as regards persuasive oral presentations?)* reveals students' awareness about the difficulty in becoming a good persuasive communicator. Even though there was no question enquiring into the usefulness of the video-recorded presentations, students did acknowledge the validity of this technique, as these two students explain: *Definitely watching ourselves makes the issues more evident and helps us improve* (Student 8*); It was uncomfortable to see myself on the screen, but I knew it was necessary to identify my mistakes and improve for future presentations* (Student 24).

Finally, it is of paramount importance to mention that students later told the teacher in class that they had watched their video-recorded presentation several times, some even stopping and rewinding at certain points. The opportunity to view oneself summarising the important amount of work done in the entrepreneurship block enabled them to live (and re-live) the experience of communicating the innovative project, which enables them to be very precise, thorough and extensive in identifying and verbalising their strengths and weaknesses. For our current generation of students, sensitive to the power of image, this activity therefore has the potential to get to know oneself from a constructive, metacognitive stance. Therefore, it seems that mirroring one's weaknesses enhances students' self-worth and self-confidence because their perception of room for improvement points to the fact that they are embracing opportunities to learn from their mistakes.

3 SUMMARY AND ACKNOWLEDGMENTS

This small-scale study has allowed us to find out the perceived positive impact for students of self-watching and self-assessing themselves as part of an entrepreneurship project. Since both teachers underlined that the error culture in this course had to be understood as an opportunity to improve not only individually but also collectively, and without dissociating content from communication and the learning process (Wingate, 2006), students viewed not only their mistakes but also those made by their team partners', and quickly they realised how important it is for the team to act as one–given that they are all explaining the same project. Together with the teacher's customised feedback and explanation–with constant reference to their mock presentation– students appreciated the first video-recorded presentation. Having watched and assessed themselves seems to contribute to improving their oracy literacies, not only in the sense of oral communication but also in the acknowledgment of how important communication is for the promotion processes of an engineering entrepreneurship project and the impact on their future employability and career. Students have learned this as a lived experience, a personal process while doing, and not only as a final product (i.e. oral presentation as an unconnected class activity without having received any guidelines) that integrates entrepreneurial skills and oracy as crucial entrepreneurship skills for engineers.

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Are E-Assessments the Future of Assessments for Engineering Students?

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ABSTRACT

Replacing traditional examinations with electronic assessments (e-assessments), also known as digital assessments, is gaining more popularity. However, it has become controversial as people have raised serious concerns about the limitations of these e-assessments, especially when the assessments have high stakes, like the end-of-term examinations. In this paper, we have evaluated whether e-assessments will replace the traditional end-of-term exams for engineering students in the future. Although this topic is equally valid for non-engineering fields, a few factors that make it unique to engineering are discussed. Different aspects of e-assessments are critically compared to paper-based (off-print) examinations based on existing literature and experiences from personal teaching practices to assess the suitability of these assessments. Furthermore, feedback is collected from students who appeared in the e-assessments to form an opinion on the perception of students about e-assessments. Finally, the factors influencing a shift toward e-assessments and the problems that arise from this are discussed to form an opinion about the future of e-assessments for engineering students.

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1 INTRODUCTION

Electronic or e-assessments are digital evaluations used to measure learners' understanding, skills, knowledge, or performance. They can be in various formats, such as quizzes, tests, assignments, or interactive activities conducted through online platforms or digital tools. E-assessments provide immediate feedback, promote personalized learning, and enable educators to track and analyze learners' progress effectively.

The popularity of e-assessments has increased significantly in recent years, which can be attributed to the shift in the learning habits of modern-day learners. While the concept of digital natives and digital migrants proposed by Prensky (2001) has been challenged by people who argue that an age-based classification of learners is not valid (ICDL, 2014), there is a consensus that learners who grew up using electronic devices learn differently than those before them. As a result, the digital transformation of learners is pedagogically significant (Beetham and Sharpe, 2013) and cannot be ignored.

To adapt to this digital transformation of the learners, Siemens (2005) has proposed the learning theory of Connectivism, which emphasizes the mode of learning and how information can be accessed using modern technology rather than the information itself. Siemens (2005) argued, 'The pipe is more important than the content within the pipe'[pg.7]. This theory has led to an increase in the use of technology for evaluations and feedback. However, many other factors need to be evaluated to understand the increased popularity of e-assessments and their potential to replace traditional off-print (paper-based) examinations.

In this paper, the authors have discussed how they have adopted e-assessments and the key advantages and challenges of using these assessments. It can benefit the teachers teaching engineering courses considering using these assessments in the future.

2 METHODOLOGY

2.1 Study Design

This paper employed a mixed-methods approach, incorporating reflection from the practices of the authors and a survey administered to students. The study aimed to investigate the students' preferences and perceptions regarding e-assessments compared to off-print assessments.

2.2 Participants

The participants in this study were engineering students who had experienced both e-assessments (midterm assessments) and paper-based end-of-term examinations. The survey was distributed to the same students who had completed both types of assessments to gather their opinions and feedback.

2.3 Data Collection

A survey was designed to collect data from students who had experienced both e-assessments and paper-based examinations. The survey included questions about students' preferences for off-print vs e-assessments (Question 1), if they want to have more e-assessments in the future (Question 2), their perceptions of e-assessments reflecting their understanding of course material (Question 3), and the impact of quick feedback from e-assessments on their learning and preparation for end-of-term assessments (Question 4). The survey also allowed students to provide additional comments about e-assessments.

2.4 Data Analysis

The quantitative data collected is presented in this paper to highlight student preferences. In addition, qualitative data in the form of student comments were also collected. The responses to each question were coded to identify key themes and patterns in the data. A summarising paragraph is written for comments for each survey question. It is used for conclusions and insights into the preferences and perceptions of students regarding e-assessments.

2.5 Ethical Considerations

Appropriate ethical considerations were followed during the research, including obtaining informed consent from the participants and ensuring confidentiality and anonymity of the responses.

3 Using E-Assessments - A Reflection on Practice

The role of assessments in shaping student workload is a critical consideration. As a result, the type of assessments used can significantly impact how students manage their learning. For example, having multiple low-stakes assessments throughout a course can be more effective than a single high-stakes exam at the end of the term, as it allows for more opportunities to provide feedback to students (Boston, 2002).

High-stakes assessments are testing methods that have significant consequences for the test-taker based on the outcome. They are often used to make important decisions about a student's academic progression, such as grades, promotions, graduation eligibility, or college admissions. An example of a high-stakes assessment could be a final examination.

Low-stakes assessments, on the other hand, carry less immediate or significant consequences for the test-taker. These assessments often include quizzes, homework assignments, in-class activities, or informal checks for understanding. Low-stakes assessments also allow students to reflect on their learning and improve their performance. Additionally, course instructors can use the results of these assessments to adjust and tailor their delivery of course content based on student performance.

However, incorporating more frequent assessments into a course can substantially increase the marking workload for instructors. This has motivated many educators to consider automatically marked e-assessments as a solution which can help reduce the marking burden. Reducing the marking workload has been critical in the recent shift towards e-assessments.

We experienced similar challenges in incorporating distributed assessments into a curriculum. When our department revised its curriculum, we aimed to provide more feedback points to students and move away from relying solely on high-stakes end-of-term exams. We found that the feedback from traditional exams, which only provides marks at the end of the year, is not always helpful to students. However, implementing distributed assessments is challenging, especially in large courses with hundreds of students. To address this challenge, we adopted automatically marked e-assessments for mid-term exams. This allowed us to provide more frequent assessments without overburdening instructors with marking responsibilities.

Although we began using e-assessments before the pandemic, the closure of universities during the pandemic resulted in a significant increase in the use of e-assessments, particularly unproctored e-assessments for both mid-term and end-of-term exams. While some were sceptical about the efficacy of e-assessments, the need to adapt to remote teaching forced many instructors to experiment with new assessment methods. However, it is worth noting that most of the exams conducted during the pandemic were not technically e-assessments but rather traditional paper-based tests delivered through a virtual learning environment (VLE). Nonetheless, this experience has inspired some instructors to explore more advanced forms of e-assessment. Our experience of these assessments was very similar to the findings reported by our colleague from the chemical engineering department in our College (Bhute et al., 2020).

3.1 Suitability for Engineering Students

Although e-assessments can be used in all fields, some factors make them more suited to engineering students. Based on the authors' experiences, engineering examinations usually involve problem-solving, system analysis and design, and programming questions. The answers to these questions are mathematical expressions, computer algorithms, and diagrams that can be marked by a computer automatically. So, many traditional examination questions in engineering disciplines can be easily marked using e-assessment software, and we do not need to design new questions to move from conventional paper-based assessments to e-assessments. The same question banks can be used. We use a software called 'Wiseflow' that allows us to use traditional examination questions on an online platform features. It significantly reduces the marking workload of the teachers and provides instant feedback to the students.

Similarly, more extensive analysis and design questions in engineering are usually modular in structure. They can be easily broken down into smaller questions that are more manageable and easier to mark for correctness using marking software. In addition, engineering examinations traditionally have very few descriptive questions. Even if descriptive questions are on a test, most other questions can be marked automatically, and the marker only has to mark the descriptive questions.

Another important feature of e-assessments for engineering students is the ability to change the numeric parameters in questions for each student. This is especially attractive for engineering students and is unique to STEM subjects that involve problem-solving, where the answer depends on the question's numeric parameters, so each student must find a different answer. We extensively use this feature to stop collusion during tests, especially if the tests are unproctored. However, one limitation of this method is that if a question has a sequential structure where the end calculations depend on the results from the initial computations, a small mistake in the initial steps can result in the complete solution being marked as wrong by the automatic marking software.

3.2 Comparison of Student Performance

The suitability of e-assessments as a direct substitute for off-print tests depends on how students perform in both types of assessments. We were very concerned about it. According to the study by Ardid et al. (2015), students' performances in terms of marks are comparable in both off-print and e-assessments under proctored conditions. The weightage of e-assessments did not affect student performance, but the weightage of off-print exams was significantly higher. However, the study cannot provide conclusive evidence as e-assessments were conducted during the term. All off-print exams were conducted at the end of the term, and the students were better prepared at the end of the term. We also have the same problem. All our e-assessments are conducted as midterm examinations. In contrast, the end-of-term examinations are mostly off-print, except for only two end-of-term exams, which are e-assessments.

Studies conducted during the Covid-19 pandemic cannot be considered valid for comparison with studies conducted before the pandemic. Most teachings during that time were also online, affecting student performance in e-assessments, especially in engineering education, where many learning outcomes depend on spending time in a laboratory and working on group projects. Several studies are available on students' performance in high-stakes e-assessments during the pandemic, but they cannot be generalized. The study by García-Alberti et al. (2021) reported that students who achieved high grades during in-person teaching also performed well on online electronic examinations. In contrast, the students who achieved lower grades in in-person assessments were affected more, and their performance was worse than the off-print examinations in the previous year. In addition, much larger percentages of students failed and dropped out when teaching and assessments were conducted online. Overall, student performances did suffer in e-assessments during the pandemic, but how much of that was due to the nature of the assessment and how much was due to the different modes of teaching is yet to be determined. Our student performances were similar to the results reported by García-Alberti et al. (2021).

3.3 Limitations of E-Assessments

We identified some severe limitations of e-assessments compared to traditional paper-based examinations based on our practice. The e-assessments require stricter authenticity, reliability, and validity requirements, making them more difficult to implement and adjust to than traditional assessments. While e-assessments can improve content validity, they may lack face validity, which can affect students' confidence (Dent et al., 2021). Additionally, transitioning to e-assessments requires more time and effort, and teachers need significant support to design assessments.

The e-assessments' construct and predictive validity can be improved through better question design and questioning formats, but this requires a shift in the mindset of both students and teachers. For example, the students may prefer traditional numerical and derivation questions to qualitative ones that test their understanding more deeply.

E-assessments also require a significant amount of technology, which can pose a challenge for students and staff, who need practical training on the software before conducting high-stake assessments.

4 Feedback from Students About E-Assessments

After reflecting on our experience, we surveyed to estimate how the students perceived these assessments. Please note that these students appeared in both off-print and e-assessments. The key findings are summarized in this section.

4.1 Quantitative Analysis

The quantitative results of the survey are summarized in this section. They are shown in Figure 1. Out of the 87 participants, 50 (57.47%) preferred electronic assessments, while 27 (31.03%) did not prefer them. 10 (11.50%) participants were unsure. It indicates that a majority of the participants had a positive view of electronic assessments.

Similarly, out of the 87 participants, 47 (54.02%) said they would prefer to sit more electronic exams in the future, while 30 (34.48%) said they would not prefer to. 10 (11.50%) participants were unsure. This suggests that most participants are open to taking more electronic exams in the future.

Also, out of the 87 participants, 48 (55.17%) said that electronic assessments accurately reflected their understanding of the course material, while 25 (28.74%) said that they did not. 14 (16.09%), participants were unsure. This suggests that electronic assessments may not accurately assess all students' understanding of course material.

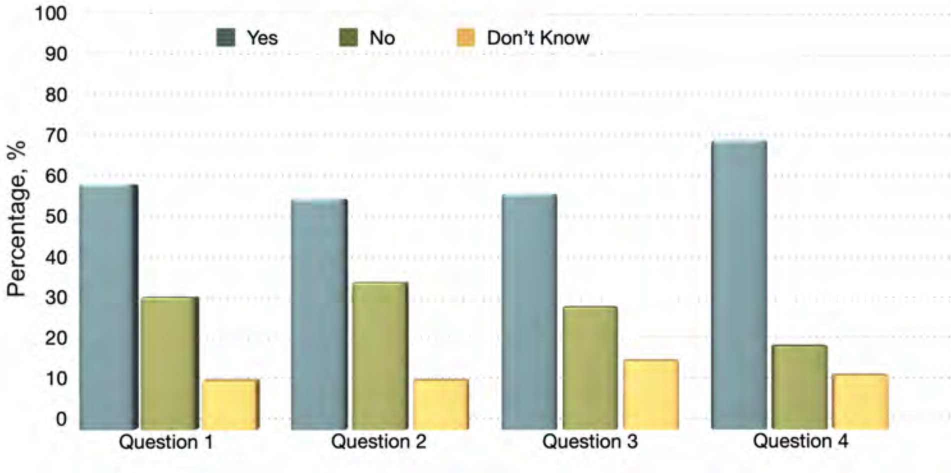

Figure 1: Quantitative results of the survey questions. Question 1: Do you prefer e-assessments as compared to off-print assessments? Question 2: Do you want to have more e-assessments in the future? Question 3: Do e-assessments correctly gauge your learning of the course material? Question 4: Do you find quick feedback from e-assessments useful?

Finally, out of the 87 participants, 59 (67.82%) said that the quick feedback from electronic assessments helped them gauge their learning and improve, while 17 (19.54%) said that it did not. 11 (12.64%) participants were unsure. This indicates that most participants found the quick feedback from electronic assessments helpful.

Overall, the results suggest that a majority of participants prefer electronic assessments and would be willing to take more electronic exams in the future. However, there may be some concerns about the accuracy of electronic assessments in reflecting students' understanding of course material. Nevertheless, the quick feedback provided by electronic assessments is generally seen as beneficial for students to gauge their learning and improve.

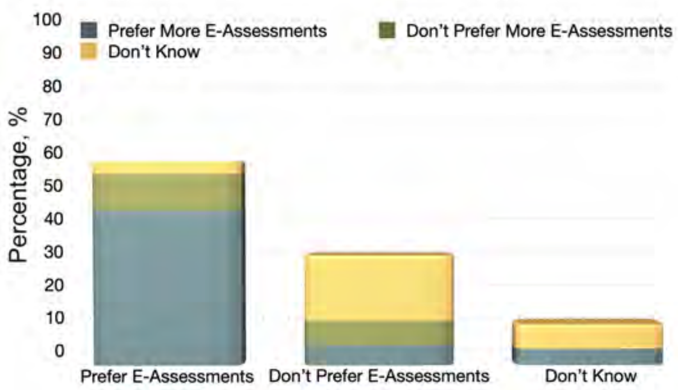

Figure 2: Preference for sitting more E-Assessments in the Future.

Several notable patterns emerged from the data. For instance, as shown in Figure 2, out of the 50 students surveyed who expressed a preference for electronic assessments, only 38 (or 76%) indicated that they would like to have more electronic assessments. Surprisingly, 9 students (18%) reported that they did not want more electronic assessments despite their stated preference for this type of assessment. Another 3 students (6%) responded that they were unsure whether they wanted more electronic assessments.

Similarly, although it is not shown in a figure here, 48 students reported that they believed electronic assessments effectively measure their understanding of the material. However, of those 48 students, only 36 (or 75%) found the feedback provided to be useful. In contrast, 7 students (14.58%) did not find the feedback useful, while 5 students (10.41%) were unsure about its usefulness.

4.2 Qualitative Analysis

For all survey questions, qualitative data like student comments were also collected. The responses to each question were coded to identify key themes and patterns in the data. In addition, a summarising paragraph is written for comments for each survey question. It is used for conclusions and insights into the preferences and perceptions of students regarding e-assessments. Detailed qualitative data analysis will be presented later, in another paper,along with data from staff interviews. Therefore, it is not included in this paper. The summarising paragraphs based on student comments are given below:

- Question 1: Many factors influence students' preference for off-print vs e-assessments. For example, some students prefer e-assessments because they allow for using notes (sometimes) and provide quick feedback. In contrast, others prefer off-print assessments because they feel more legitimate and eliminate issues with cheating and technology. Additionally, some students may find that e-assessments are less stressful and more convenient, while others feel that off-print exams are better for assessing understanding and avoiding mistakes. Ultimately, the choice between e-assessments and off-print assessments may depend on the specific exam and the test taker's individual preferences and circumstances.
- Question 2: There are various reasons why students might prefer to have more e-assessments in the future, including convenience, reduced stress, accessibility, and faster feedback. However, concerns about cheating, the fairness of the exams, and technical issues may arise. Therefore, balancing these factors is essential to increase the number of e-assessments in the future.
- Question 3: Based on the student responses, students have varied opinions on the effectiveness of e-assessments in accurately reflecting their understanding of course material. Some students feel that e-assessments are a better way to test their understanding of the material since they focus on application rather than memorization. In addition, they think these e-assessments are often open-book exams, allowing for a clearer thought process. In contrast, other students feel that e-assessments have poor question format and do not provide credit for workings, which can negatively impact their grades and understanding. Overall, students have different experiences with e-assessments and the effectiveness of e-assessments in accurately reflecting student understanding of the course material depends on various factors such as question format, time constraints, and personal preferences.
- Question 4: Based on the student responses, most students find e-assessment exams helpful for getting quick feedback on their performance. They appreciate seeing where they made mistakes and what areas to improve. However, some students feel that the feedback is too minimal and that more explanation would be helpful, especially for more complicated questions. The difference in question style between mid-term exams and end-of-year assessments was also noted as a potential limitation. Additionally, some students feel that not enough feedback is given by their professors for the end-of-term off-print exams, so the e-assessment midterm exams provide valuable feedback.

5 Conclusion

The quick feedback provided by electronic assessments is generally seen as beneficial for students to gauge their learning and improve. However, there may be some concerns about the accuracy of electronic assessments in reflecting students' understanding of course material. Providing more explanation and feedback for complicated questions in electronic assessments may help students better understand their performance and improve their learning. Based on the results, most student participants prefer e-assessments and would be willing to take more electronic exams in the future. Their choice is mostly based on the quick feedback they get. In addition, most teachers are also opting for e-assessments due to the flexibility in assessment design and a reduced marking workload.

Overall, the results suggest that electronic assessments have benefits, but some limitations must be addressed. Further research could investigate ways to improve the accuracy of electronic assessments and address concerns about cheating, fairness, and technical issues. At the moment, the choice between off-print and electronic assessments may depend on the specific exam and the individual preferences and circumstances of the test taker, but surely, with the development of assessment software, e-assessments will completely replace paper-based examinations as they are prefered both by students and staff for different reasons discussed in this paper.

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Enhancing Engineering Students' Mathematics Learning Through Digitised Effective Feedback

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ABSTRACT

This practice paper explores the impact of effective digitised feedback on engineering students' mathematics learning in the digital environment. By using a schematic framework, an online repository will be developed to provide effective feedback to the first-year students taking mathematics courses. The repository takes into account calculus topics and focuses on providing guidance to students who give incorrect answers to questions by incorporating sub-questions based on Polya's heuristics. The sub-questions aim to motivate students to draw on simpler connections and stimulate learning by encouraging students to check their answers and reflect on their initial responses. This study is currently an ongoing project in the Netherlands and aims to improve outcomes in calculus courses and provide a database of online exercises for digital exams, which will save teachers time, in long term.

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1 INTRODUCTION

In recent years, the integration of technology into education has become increasingly prevalent, transforming traditional learning environments and offering new opportunities for innovative instructional approaches. Engineering education, in particular, has witnessed the incorporation of digital tools and platforms to enhance the teaching and learning process. Within this context, the focus on mathematics learning and the provision of feedback have emerged as critical areas of investigation. By leveraging the potential of digital platforms, this study aims to enhance the effectiveness and engagement of students in their mathematical studies.

Recent advancements in educational technology have paved the way for the development of digitised effective feedback systems that go beyond conventional feedback mechanisms. The MAA National Study of College Calculus conducted by Bressoud, Mesa, and Rasmussen (2015) provides valuable insights and recommendations for implementing effective feedback strategies in college-level calculus courses. Their findings emphasise the importance of timely and constructive feedback in enhancing student learning outcomes.

In addition to the cognitive aspects of learning, the effective dimensions, including students' emotions and engagement, play a crucial role in the learning process. Research by Pekrun, Goetz, Titz, and Perry (2002) and Fredricks, Blumenfeld, and Paris (2004) explores the influence of effective feedback on students' self-regulated learning and engagement. Understanding and addressing students' effective experiences through digitised feedback can contribute to creating a supportive and motivating learning environment.

To guide students in their problem-solving processes, this study also draws upon the principles of Polya's problem-solving heuristics. Kilpatrick, Swafford, and Findell (2001) discuss the importance of problem-solving skills and approaches in mathematics education in their influential book "Adding It Up: Helping Children Learn Mathematics." By incorporating Polya's problem-solving heuristics, educators can empower students to develop essential problem-solving skills, fostering a deeper understanding of mathematics.

In conclusion, this paper addresses the pressing need to explore the potential of digitised effective feedback in mathematics learning within the context of engineering education. By building upon existing scholarship, including recent advancements, key papers, and notable research, and leveraging theoretical frameworks, the study aims to contribute to the field's knowledge base. The findings of this research will inform the development of an online repository of questions and exercises that integrate effective feedback, offering valuable resources to the SEFI community and advancing the learning experiences of engineering students in mathematics courses.

1.1 Research Question

Based on the above considerations and the need to enhance mathematics learning in engineering education, this study aims to investigate the impact of effective digitised feedback, incorporating sub-questions based on Polya's heuristics, on engineering students' mathematics learning in the digital environment. Therefore, the main research question is: What is the impact of effective digitised feedback on engineering students' mathematics learning and problem-solving abilities? To address this question comprehensively, this paper will undertake an exploration of the subsequent inquiries: How do these sub-questions based on Polya's heuristics contribute to the resolution of the main problem, and in what ways can their efficacy be further enhanced? Interviews were conducted with two first-year students, denoted as a student with intermediate proficiency (SIP) and a student with low proficiency (SLP), whose feedback has been presented in the results section of this paper.

2 METHODOLOGY

Since 2020, the University of Twente (UTwente) has been utilizing the Grasple online learning platform[1], which offers hint-based feedback to students through exercises sourced from other technical universities in the Netherlands. Course evaluations have consistently indicated that students are highly satisfied with the use of this online platform. However, there is a pressing need to enhance the exercises available in the Grasple repository to align them more closely with the specific learning objectives of UT's Mathline courses.

The aforementioned repository takes into consideration calculus topics, such as vectors, limits, and derivatives, which are part of an ongoing project called the 4TU Teaching and Learning Fellowship at UTwente. The aim of this project is to develop constructive feedback mechanisms for students by improving the existing repository of questions and creating new ones. The main focus is on providing sub-questions that can guide students who have given incorrect answers, serving as stepping stones to help them overcome challenges in problem-solving. These sub-questions are developed by the researcher based on relevant literature and their own teaching experience.

To guide the development of sub-questions, the framework of Polya's heuristics (1957) and Schoenfeld's metacognitive aspects of successful problem-solving (1985) are taken into account. Polya's heuristics emphasise understanding the problem, devising a plan, executing the plan, and reflecting on the solution as key steps in effective problem-solving. The heuristics offer students systematic approaches, such as working backward, drawing diagrams, making assumptions, and considering special cases, to enhance their problem-solving skills.

In Figure 1, an example from Grasple is presented, focusing on the creation of a plane equation using given vectors. The hint-based feedback is provided to students when they answer the question incorrectly, aiming to facilitate their learning process. Inspired by Schoenfeld (1985), the strategy of solving an easier, related problem first is employed as a means to support students in tackling the original problem. The sub-questions act as stepping stones and encompass concepts such as the dot product, vector construction, and visualizing components.

Another important aspect in problem-solving, as advocated by Polya, is the step of looking back. This encourages students to review their answers, analyzing them for accuracy and reasonableness. It also provides an opportunity for students to reflect on their initial responses and approach the problem with a more conscious consideration. This step will be integrated at the end of the sub-questions to further

[1] Grasple. "Homepage." Grasple. https://www.grasple.com/.

support students' learning process. Table 1 provides an overview of the sub-questions based on the guide to problem-solving techniques outlined in Polya's work (1957).

By incorporating these research-based strategies, our objective is to enhance students' mathematical learning experiences and improve their problem-solving abilities within the Grasple platform. To measure the effectiveness of our approach, we will interview a larger sample of engineering students after introducing the sub-questions in their studies. Additionally, we will compare the passing rates with the previous year's data. This expanded sample will provide valuable insights into the impact of effective digitised feedback on their mathematics learning and problem-solving abilities. Through the development of effective sub-questions and the integration of Polya's heuristics and Schoenfeld's metacognitive aspects, we anticipate creating a more comprehensive and engaging learning environment that fosters students' growth and success.

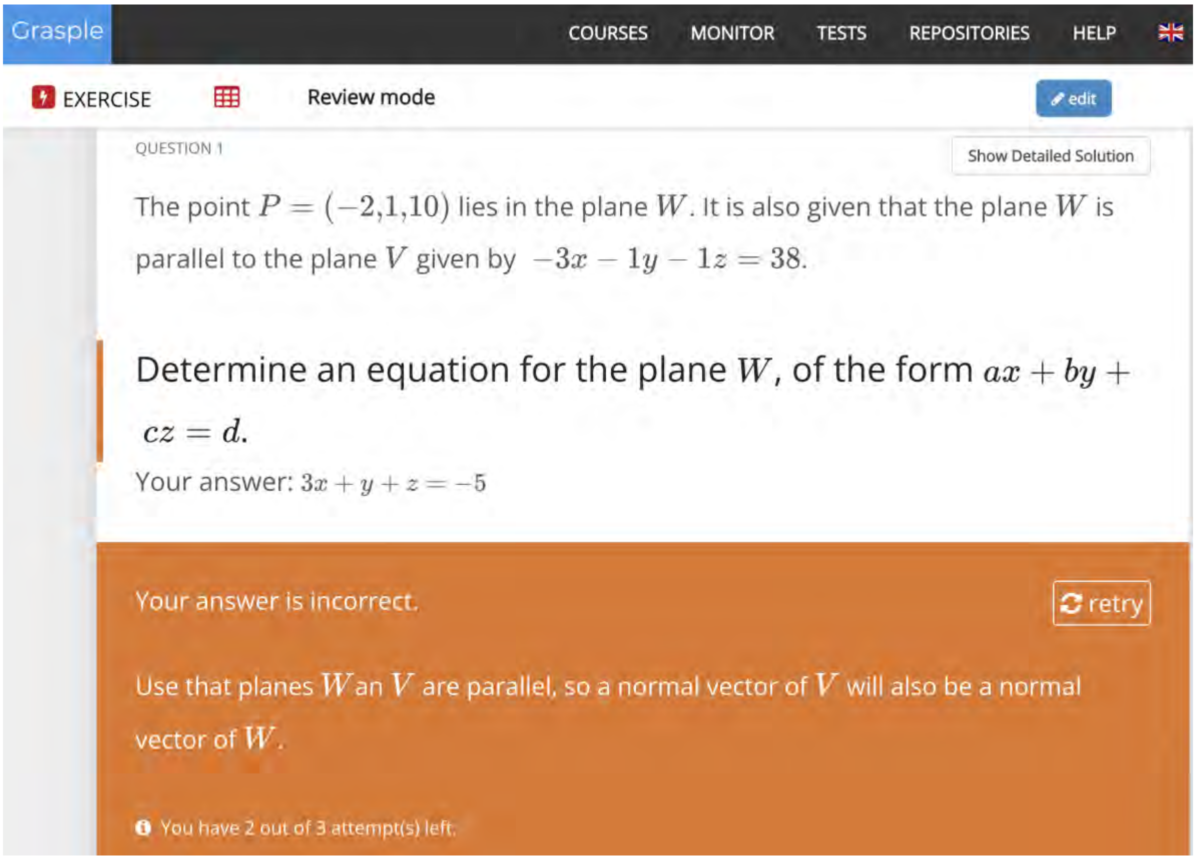

Fig. 1. The original final answer question with a hint due to incorrect answer on Grasple.

Table 1. The sub-questions by using the guide to problem-solving techniques (Polya 1957).

Phases	The sub-questions with Heuristic Approaches
1. **<u>Understanding the problem:</u>** Polya emphasises the significance of understanding the problem before attempting to solve it. This involves reading the problem carefully, identifying the given information, and clarifying the desired outcome.	**Sub-question 1: Understanding the given information (Relating Planes):** Before tackling the original problem, it is essential to determine the given information. The final answer sub-questions could be: • Which point lies in the plane W? • Which equation represents the plane V that is parallel to the plane W?
2. **<u>Devising a plan:</u>** Polya highlights the importance of devising a plan or strategy for solving the problem. This involves breaking down the problem into smaller, more manageable parts, recognizing patterns or similarities to previously solved problems, and considering alternative approaches.	**Sub-question 2: Determine the normal vector of plane V:** Understanding the concept of a normal vector and its relation to a plane equation is essential for solving the original problem. This sub-question helps reinforce the connection between normal vectors and plane equations. The sub-questions could be: • Which vector is perpendicular to the plane V? a) (-3,1,1) b) (0,-1,1) c) (-3,-1,-1) d) (1,0,-3) **Sub-question 3: Visualizing the components:** Visualise the components of the vectors and their relationship in three-dimensional space. This step helps in understanding the geometric interpretation of the plane equation.The sub-question could be: • Which of the following statements is true about the two parallel planes? a) Their respective normal vectors are parallel. b) Their respective normal vectors are perpendicular.

	Sub-question 4: Identify the relationship between parallel planes: Understanding the relationship between parallel planes is crucial for solving the original problem. By exploring this sub-question, the student will develop a deeper understanding of how parallel planes are related in terms of their normal vectors and equations. The sub-question could be: • Determine the normal vector of the plane W. a) (0,-1,1) b) (-3,-1,-1) c) (1,0,-3) d) (-3,1,1)
3. <u>Carrying out the plan:</u> Once a plan is formulated, Polya advises students to execute it step by step, applying appropriate mathematical concepts and techniques. He encourages students to be flexible and willing to revise their plan if necessary.	**Sub-question 5: Dot product calculation:** Calculate the dot product of the constructed vectors. The dot product is a crucial operation when working with vectors and plays a big role in defining planes.The sub-question could be: • Using the point P=(-2, 1, 10) and the normal vector of the plane W, determine the equation of the plane W. a) 2x-y-10=38 b) -3x-y-z=-5 c) -2x+y+10=38 d) 3x+y+z=-5
4. <u>Looking back:</u> After obtaining a solution, Polya suggests reflecting on the problem-solving process. This includes verifying the solution's accuracy, assessing the reasonableness of the answer, and considering alternative methods or perspectives.	**Sub-question 6: Reflecting on the solution:** This question prompts the student to substitute the coordinates of point P into the equation of plane W and determine if the equation holds true for the given point, without explicitly providing the direction (positive or negative) of the statement. The sub-question could be: • Verify if the point P=(-2, 1, 10) lies on the plane W represented by the equation ax + by + cz = d.

		a) Yes, the point P lies on the plane W. b) No, the point P does not lie on the plane W.

3 RESULTS AND DISCUSSIONS

In the following section, we will present the outcomes based on our interpretation of the extracts obtained from the conducted interviews. Each interview lasted approximately 45 minutes and was recorded for accurate documentation. The Grasple question depicted in Figure 1 was given to two first-year engineering students at UTwente: a student with intermediate proficiency (SIP) and a student with low proficiency (SLP). Initially, both students encountered difficulties in solving the main problem. However, upon the introduction of the sub-questions aligned with Polya's heuristics, both students successfully arrived at the correct answer. The interview encompassed a concise set of approximately two questions, namely: (1) How do these sub-questions based on Polya's heuristics contribute to the resolution of the main problem? and (2) In what ways can their efficacy be further enhanced?

<u>(1) How do these sub-questions based on Polya's heuristics contribute to the resolution of the main problem?</u>

- Overall: "*I would say in general it was a lot better than the Grasple right now. Because I know a lot of people are getting frustrated when they make a small mistake or a big mistake, whatever, and then it just says you're wrong and the explanation is not super clear. Or for example, the explanation assumes that you know something and just skips that part […] and some people just I know what we're trying to just learn how to solve what Grasple wants you to solve and that didn't seem right, but this seems a lot better […] it's like takes your hand and just follows you through the whole thing." (SIP). "I like them, because you could see it [the solution] step by step."(SLP).*

- Regarding the first phase: *"People make a lot of mistakes when reading and a lot of times you fail to solve for Grasple because you just didn't finish the sentence because you know you already know what's gonna be there. But it's not there."(SIP). "Well, these are mostly the questions that I ask myself first, so I write them down first of all.[…] That's the basic step to start any question, just write everything down that's asked from the question itself."(SLP).*

- Regarding phases 2 and 3: *"I think you can definitely see the correlation to the original equation. So we should be able to make the connection."(SIP). "So it's a good continuation on your thought process about entering question 4 from question 2." (SLP).*

- Regarding the last question: *"I like the last question because it forces you to double check your work, which people always not do, and it's a good habit to force people to do it and maybe they will actually end up doing it in their life. So* *that's nice." (SIP). "It's a nice finisher, because then you can see, OK, the point P does fit into the correct formula which you answered and if I answered [question] 5 incorrectly, then it wouldn't work."(SLP).*

(2) In what ways can their efficacy be further enhanced?

- Point of improvement: *"Maybe not these questions themselves, but like if the question is way more complex and if a person does not know the theory and he gets more like he tries, it gets wrong. Maybe it's great if it would kind of give you a short theory where referring to for example. it would be nice if it, like gives you that, but only if it's like a complicated thing […] So you make a mistake, right? You double check your work and then you saw correctly. Then you don't need the theory. But if you make two mistakes in a row, I guess then it's nice for you to get the theory." (SIP). "[In Phase 2] I would like to see some theory about it, and maybe a 3D visualisation on why the numbers are connected. […] Yes, for me it's clear, but I made a 3D visualisation in my head where I had two planes and if you have two perpendicular vectors, one from the plane downwards up or one from the plane. They [normal vectors] are parallel."(SLP).*

Based on the students' feedback, we discern a positive interpretation, highlighting the advantages associated with the implementation of the sub-questions. The interview outcomes reveal that both phase 1, involving the understanding of the given information, and phase 4, related to the reflection on the solution, play significant roles as essential stages in assisting students in resolving the main problem. In light of this feedback, we are committed to diligently considering their recommendations for enhancing the project.

This study is anticipated to yield substantial improvements in outcomes for calculus courses, which are essential components of various study programs at the University of Twente. Additionally, it aims to establish a comprehensive database of online exercises that can be utilized for digital exams, resulting in considerable time savings for teachers. The project's timeline indicates that the outcomes for larger interview sample will be available by the end of the first quarter of the upcoming academic year allowing us to address our main research question. This project introduces a practical and innovative approach to providing effective feedback to engineering students, thereby significantly enhancing their learning experience and preparing them for the challenges of a complex and sustainable world. Further research has been conducted, and additional examples will be presented and discussed during the Poster presentation of this study at SEFI 2023.

4 ACKNOWLEDGMENTS

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INSTRUCTIONAL CONSIDERATIONS FOR VIRTUAL REALITY IN ENGINEERING TRAINING AND EDUCATION: PRELIMINARY RESEARCH RESULTS

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Conference Key Areas: *Engineering Skills and Competences, Virtual and Remote education in a post Covid world.*
Keywords: *Virtual Reality, Engineering Education.*

ABSTRACT

Digital reality has been gradually introduced into all parts of human society, and the field of education is no exception due to the potential of technology and related tools to enhance the teaching and learning process. However, there is still a paucity of research in this area within an Irish higher education context.
The research explores how to best employ virtual reality (VR), using the Oculus Quest 2 system, to improve and develop the level of contemporary training, as well as to enhance the educational experience. Both the technical and educational perspectives will be considered.
The researched sample consists of 25 undergraduate students representing different profiles from within engineering education. The data collection included two stages, namely written questionnaires, and short semi-structured interviews relating to training sessions with Oculus Quest 2, in which participants were exposed to life on board the International Space Station (ISS), including the experiments and missions performed on the station.
The results of the short interviews and questionnaires extracted in this work reflected that all the participants were very excited to work and interact with the experiences of virtual reality in engineering education. In addition, they rated the usability of virtual

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reality glasses overall as being very satisfactory, despite some students expressing the presence of minor challenges or problems.
Most of the participants' reactions were positive regarding the possibility of including virtual reality devices and associated technologies in future training and support, as they indicated that these training sessions increased their motivation and passion for learning, whilst at the same time, supported the development of their digital reality skills.. In general, the outputs of the research show that the inclusion and empowerment of digital reality within higher education programmes can have significant value and benefit, leading to the recommendation that it would be used more extensively in the future.

1 INTRODUCTION

Digital tools based on virtual reality (VR) technologies have witnessed a remarkable expansion in recent times, especially with the increase in features and characteristics available and their relative ease of use. The popularity of these technologies has increased rapidly in the field of games platforms, in addition to gaining traction within the fields of education and health care training (W. Werner et al. 2007 and R. Jaziar et al. 2020). Additionally, its unique features, such as the sense of presence and the immersive experience of losing connection to the physical world, have led to creating new interest for users (R. Jaziar et al. 2020 and W. Peng 2018).
It is worth noting that the non-prohibitive cost of such technologies has allowed researchers to use and work on developing specific applications suitable for use in academic environments (Y. Zinchenko et al. 2020 and D. Carruth 2017). In addition, these technologies represent a good alternative or complementary solution for some complex, sensitive and expensive engineering devices and laboratories (Z. Zacharias et al. 2014, K. Winkelmann et al. 2020 and G. Mosquera et al. 2018).
This research work presents the means by which the VR equipment (i.e., the Oculus Quest 2 system consisting of a VR headset (head-mounted display) and two controllers) was used as a support tool in engineering education to enhance the current learning approach. Also, the work focuses on how to incorporate learning theories during the selection or design of virtual reality (VR) applications. Equally, this would allow for the development of a general framework for building, managing, examining and evaluating VR technologies that are designed within specific areas of engineering education.
The promising results of this work may open creative ideas towards establishing the technical and educational foundations for remote learning, which provides an opportunity for higher education institutions (HEIs) to engage in knowledge sharing and co-creation on an international basis.
In that respect, there are potential benefits from an educational perspective of integrating virtual reality technologies into the curricula. In terms of context, the current work sheds light on the benefits and challenges that the students faced during training sessions, as a case study in the Faculty of Engineering, South East Technological University (SETU), Carlow, in Ireland.
The work will focus on addressing the following sub-questions in the context of the current work under the project name “CarlowENG-VR1.0”:

1- From the perspective of the students, what is the effect of using virtual reality on their motivation and engagement?
2- In terms of educational setting and preparations, what should be considered when developing educational programmes that employ virtual reality?

3- What are the additional and unique features that VR environments offer in terms of pedagogical ?
4- How will the VR headsets (i.e., head-mounted display "HMDs" combined with multi-axis inertial measurement unit "IMUs") support the learning process and the development of attendant exploratory skills, from the perspective of the students?

In the next section. the project details and selected results will be presented, based on the experience gained, and the possibilities to employ a suitable digital reality system will be explored.

2 MATERIALS AND METHODS

2.1 Participants: Undergraduate Students

Undergraduate students from a range of engineering-related programmes, inter alia, electronics, and aerospace engineering, were notified regarding this project and were invited to participate on a voluntary basis. The invite was circulated to a total of 35 students, of which 25 opted to be involved and we can be confirming that informed consent was obtained from all 25 participants for these experiments. SETU Carlow Research Ethics Committee confirmed this project is compliant with statutory requirements and is conducted to the highest ethical principles.

2.2 Research Design

Each student who participated received project information and data collection debriefing over a number of days, in the second semester of the academic year 2022-2023. Each session lasted approximately 30 minutes and included the following activities:

1- An initial project information session by means of a short PowerPoint presentation (approximately 5 mins);
2- An initial individual, paper-based survey that had to be completed by each participant before using an immersive VR training session – survey completion time (5-7 mins);
3- A demonstration of the handling of the VR equipment (5 mins),
4- Individual guidance with the VR equipment according to the required training task (10-15 mins); and
5- A second individual, paper-based survey and a short interview with each participant (5-10 mins).

2.3 Contents and Framework of the Training Session

There are several educational perspectives that can be considered in engineering education and in this context, the chosen topic of the training session was selected based on the following two criteria:

(1) It should be of interest to prospective engineering students; and
(2) It should be based on digital reality (i.e., VR tools), in that it should have the ability to add notable and value, in terms of simplifying the contents and being more flexible and accessible than traditional teaching methods.

To match the students' profiles, which included electronics and avionics engineering majors, the chosen topic centred on the experiments and mission exploration being performed on the International Space Station. This was seen as a suitable case study which could provide new information, knowledge and skills.

It is worth mentioning, that NASA uses these technologies for training purposes in their own Virtual Reality Laboratory (VRL), which is an immersive training facility providing

real-time graphics and motion simulators, integrated with a tendon-driven robotic device. This provides the kinaesthetic sensation of the mass and inertia characteristics of any large object (around 500lb or 226 kg) being handled (A. Guzman 2022), as shown in Figure 1a.
In all of the educational experiments conducted as part of this study, the Oculus Quest 2 system was used, which itself is a rather recent technical development. It was introduced to the markets as Meta Quest 2 at the end of November 2021. Oculus Quest 2 is a virtual reality (VR) headset that allows users to work, study, and engage in numerous life-imitating and imaginative simulations (H. Valentin et al. 2021 and A. Diar et al. 2022). In the visual output of the device, artificial objects and information can be displayed in the wearer's visual field, which can be interacted with via various gestures as shown in Figure 1b.
The selected VR training software (Mission:ISS) was designed by the L.A.-based Magnopus studio, in collaboration with NASA, the European Space Agency, and the Canadian Space Agency, where these virtual experiments create a true-to-life simulation which lets users visit and explore the International Space Station (ISS) within digital reality and feel what it is like to be in space in a way never before possible (P. James 2022).

(a) (b)

Fig. 1. (a) part of a training sessions at the 3D virtual reality laboratory at NASA's Johnson Space Centre in Houston (A. Diar et al. 2022), (b) Use of cases for Oculus Quest 2 as part of Livestream of the users' view in SETU-Carlow Campus.

Based on NASA's Space Station models, as well as discussions with multiple astronauts and the VR Laboratory at NASA's Johnson Space Centre in Houston, Mission:ISS recreates the International Space Station in painstaking detail. Whilst the idea of becoming an astronaut may be a pipedream for most, with these advanced digital technologies, the trainers can use their virtual hands to do several tasks such as, docking incoming cargo capsules, conducting spacewalks, and performing mission-critical tasks, virtually (A. Diar et al. 2022).
Through the training sessions, this visceral and interstellar experience signifies a new cornerstone of interactive education. The students have the chance to learn the history

of the ISS and hear the inspiring stories of several astronauts in a series of immersive videos. And there is another educational component to the experience, most explicitly in terms of the optional pop-ups to be found. If something is highlighted in yellow when the trainee points at it – a spacesuit, say, or a control console – they can hold the trigger to reveal text and a photo or sometimes a video. Furthermore, a NASA astronaut will talk briefly about their experiences that can help and guide the students in their first-time training sessions.
In addition, a wide range of different representations can be shown, which is not as easily possible with the more traditional basic models. The Mission:ISS software was designed to display different representations, and create different user sessions as well, which gives them opportunities to extend the training sessions and add more flexibility to select a wide range of options (A. Diar et al. 2022 and P. James 2022).
In order to be able to work with this digital environment, the training session started with a short presentation of basic concepts for graphical user interface (GUI), controller options and keys. This section was followed by an introduction to the different representations which the Mission:ISS software can display. The designed sequential procedures can be visualized in Figure 2.
Following the introduction and initial survey, the student had the chance to handle the VR equipment and work through the user interface training session of the Oculus Quest 2 device, helping them to be familiar with gestures requisite to executing a Virtual Reality HMD and two controllers.
Through the demonstration session, the students were shown how to operate the Mission:ISS software. Once the software user interface was explained, the students then worked on the specific tasks individually for approximately 10-15 minutes before completing the second paper-based survey and a short interview.
The directives given to the trainee students within the teaching/training sessions were as follows:
(a) Allow the trainee to wear a helmet while looking at computer displays, whilst simulating actual movements around the various locations on the station hardware where the real astronauts were working.
(b) Visualize and test, a zero-gravity environment using the Touch controllers, as well as examining the effects of zero-gravity on human spatial awareness and balance.

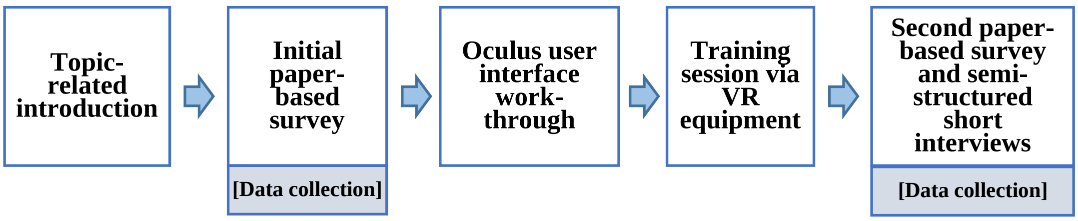

Fig. 2. Structure of the participants' programme.

2.4 Data Collection

The two written paper-based surveys were conducted as the main components of the data measuring and collection stage before analysing the research data using the standard validated tools and techniques. The essential goal of a questionnaire was to monitor and measure the participants' motivation and engagement as well as their experiences before and after using VR tools in the field of engineering education.
The two surveys contained several questions. Generally, there are three recommendations for evaluating user interface: efficiency, multiple perspectives, and tailoring which were proposed by Brooke (1996) (J. Brooke 2018 and J. Lewis 2018).

A System Usability Scale (SUS) questionnaire set for the first and second surveys was created based on these recommendations. A series of questions with multiple choices, some with a 5-point Likert scale (A. Joshi et al. 2015) response and some with text input response was created. A few examples are shown below;

1- Before testing the VR headset; In your Initial opinion, do you think this VR method is better than the traditional method of learning about concepts such as working in gravity/space environments? (Likert scale)
2- After testing the VR headset; How do you rate the user interface of the 3D video? (Likert scale)
3- After testing the VR headset; In your opinion, would this kind of VR learning app improve student learning in engineering? (Likert scale)
4- After testing the VR headset; How do you rate your level of confidence in navigating/using the app? (Likert scale)

Typically, the survey questions evaluated the effectiveness in learning/training especially complex models, features, navigation, User Interface (UI), and overall usefulness of the VR tool in achieving the learning goals.

Most of the participant's educational backgrounds were STEM, 80% of undergraduate students were male and 20% were female. The 5-point Likert scale survey questions were then analysed. After the participants had completed the work phase separately, they were individually interviewed about their experiences, their motivation, and their interests by means of a semi-structured brief interview which detailed results will be published in a separate contribution (the work in preparation).

2.5 Data Collection

The results of the two paper-based surveys were transferred into a spreadsheet software program (Microsoft Excel). Using this tool as a statistical analysis software, the data were analysed on a descriptive basis and factor analyses and correlations were calculated.

The link between the students' opinions before and after the training sessions for VR experiments can provide quantitative data and the ability to measure some factors. Additionally, it allows for the evaluation of the effectiveness of the learning approach adopted, especially in relation to the acquisition of new digital characteristics, the ability to simplify navigation of complex models, and the overall usefulness of the VR tool in helping to achieve the learning outcomes.

3 RESULTS

The results of this research work focused on the users' opinions based on the written surveys. However, some outcomes of the students' reflections will also be presented. The training included a short video explaining what the space surrounding the Earth looked like, as well as an opportunity to look at Earth from the angle of outer space. The participants were unanimous in their opinion that such immersive technologies for displaying educational films were invaluable.

Another question asked to the students focused on their opinions regarding the possibilities of including immersive 3D videos in educational programmes in order to stimulate/encourage people to increase their knowledge of planet earth and new space technologies. Figure 3a shows that 76% agreed and strongly agreed, with 20% are still neutral. Watching movies with virtual, or might even augmented, reality technologies adds new features to exploring one's surroundings, and discovering more precise details. In total 92% of the students classified the 3D-immersive video User Interface as very good, as illustrated in Figure 3b.

Another question asked to the students before and after VR experiments centred on the potential of VR programs and apps to help solve problems/achieve the goals more effectively than traditional teaching and learning strategies. After using the VR immersive tools, student satisfaction increased from 12% to reach 52%, as shown in Figure 4, which leads us to the importance of effective design when it comes to creating learning experiences, which can in turn increase the student's interest and motivations.

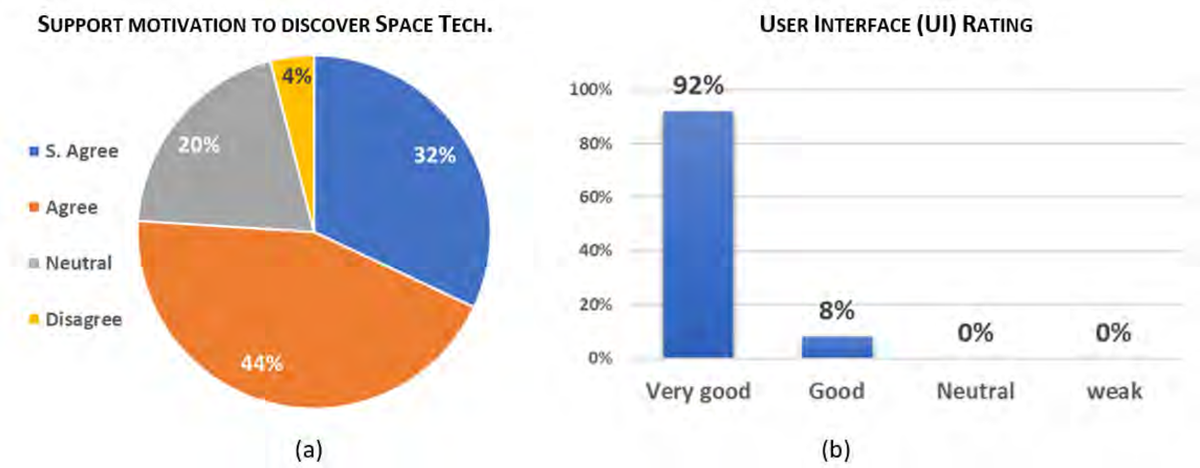

Fig. 3. Summary of the student opinions related to 3D immersive video.

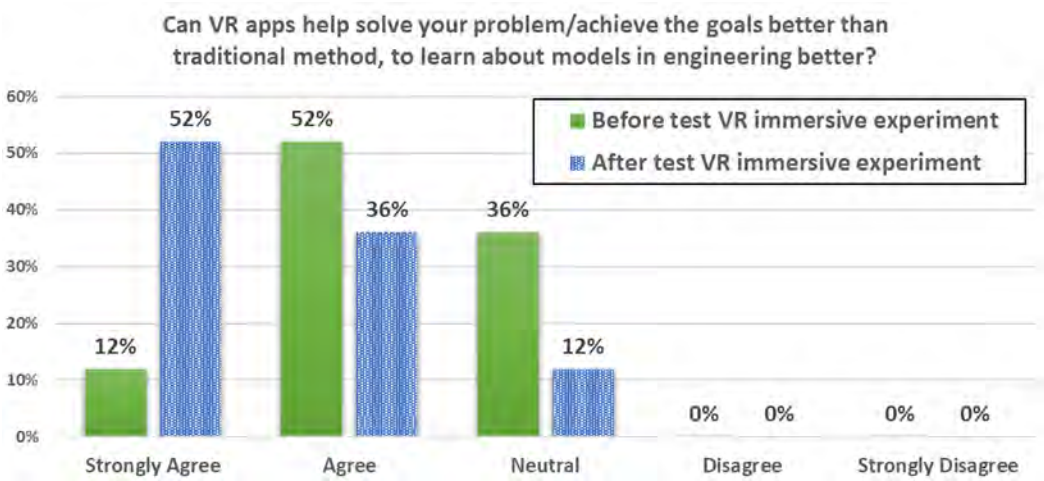

Fig. 4. User feedback before and after using VR headsets in engineering education.

4 DISCUSSION

The VR headset (head-mounted display) and 2 controllers (i.e., Oculus Quest 2 system) were used in this exploratory study as part of the engineering students' class sessions. This VR tool is a relatively new piece of equipment, having being first become available at the end of 2016. It includes a head-mounted display integrated with different high-tech sensors which can work together to support and provide innovative ways of teaching and learning. The exploration of new aspects of student engagement with VR was the focus of the study, which as noted, has been, for the most part, absent in the case of Irish engineering education. To date, there is limited research exploring the feasibility of using such wearable technologies such as bracelets, HMD (head-mounted displays) or gloves in field of higher education programmes.

The initial results related to the impact of virtual reality on learning, showed that the students enjoyed working with VR and they did not face major problems when dealing with it. The students' enthusiasm was observed during the VR sessions, particularly after completing the training part focusing on the Mission:ISS aspect and how to get around and interact with the station. Additionally, they appreciated the opportunity to employ VR devices in undergraduate education and they mentioned that their motivation and interest were augmented, and that their skills were enhanced, thereby illustrating that teaching and learning can be supported using different innovative means and employing digital reality technologies.

5 CONCLUSIONS

These kinds of training techniques and high-tech research using VR can increase knowledge creation and awareness by sparking learners' imagination, and supporting them to experience learning such as testing partial zero-gravity in the international space station, which would not have been otherwise accessible to them within the classroom.

Until the current study, there were a limited number of studies related to embedding virtual reality techniques in teaching engineering in Ireland. In this regard, the outcomes of this research work give new findings that might be related to the higher education sector in general or specifically to engineering fields. Mainly, the results explain that potential students or trainees are supportive of integrating VR technologies and related equipment in higher education programmes, especially as support tools in the laboratory.

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LMATE: AN INNOVATIVE BACHELOR DEGREE CONNECTING MATHEMATICS AND INDUSTRY

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Conference Key Areas: *Engagement with Industry and Innovation, Curriculum Development*
Keywords: *Applied Mathematics, Innovative Bachelor Degree, Partnership with Industry, Enterprise Internship, Transdisciplinarity*

ABSTRACT

The bachelor degree in Mathematics Applied to Technology and Enterprise (LMATE) has an innovative structure, working in partnership with industry, involving a transdisciplinarity curriculum plan, with a solid mathematical base including extensive knowledge in statistics, optimization, modeling and programming (Python, R, etc.), along with training in engineering, physics and management.

LMATE presents three differences in relation to other applied mathematics portuguese bachelors degrees: it was constructed upside down towards the usual,

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once partner entities (enterprises, public entities and research centers) were consulted on relevant mathematical contents to solve their problems, instead of being created exclusively by the academy; in its curricular plan has optional curricular units from several engineering areas; and is the only bachelor degree in applied mathematics that has an internship integrated.

As LMATE performance evaluation measures the following can be listed: the number of partner entities has increased to 37 currently; demand has been far greater than the offer of vacancies, reaching around 800%; average entry grades have been increasing (from 12.6 to 15.2); and more than 70 of the 176 students who entered in the six years of LMATE have graduated, having done internships in partner entities.

Based on a follow-up study of students who have already finished LMATE to assess the quality of the knowledge acquired and its employability, it is concluded that many of finalists enroll in master's degrees, the majority just after LMATE; others enter the labor market straight away, but all feel that LMATE provided them with adequate preparation.

1 INTRODUCTION

Many of the developments in our society are undoubtedly driven by science and technology, making it imperative to apply different mathematical concepts and methods, most of them driving to optimal results which increase sustainability. In 2021, the UNESCO Director-General said that mathematics support all areas and plays a key role in artificial intelligence and technological disruptions along with algorithms; when global issues such as the COVID-19 pandemic, climate change and sustainability are addressed, the importance of mathematics in responding to current challenges is perceived (UNESCO 2023).

The universe of Mathematics applications is vast, there are several areas of human knowledge, namely all natural sciences and engineering, medicine, economics or social sciences. There are also numerous branches of mathematics to which these areas apply, among which modeling, optimization, statistics or computer science, can be highlighted (Pepin, Biehler and Gueudet 2021, 166). Despite this intrinsically interdisciplinary context, the vast majority of existing classical applied mathematics bachelor degrees have, for students, an apparently limited action in applications.

Interaction with external stakeholders is highly recommended to develop students' skills and abilities. In addition, it is important to adapt students' learning to the needs of stakeholders, allowing optimizing processes and resources, as well as increasing competitiveness, and fostering the sustainability of companies/industry (Hoinle, Roose and Shekhar 2021; Gorgul and Erden 2022, 1206; Herzog et al. 2022). Faced with this reality, one of the authors, as president of Mathematics Department (MD), triggered the construction process of a new Bachelor Degree: LMATE.

2 CONTEXTUALIZATION

LMATE intends, without giving up a rigorous mathematical training, to enable its students to solve issues raised by society, by institutions and companies from several areas or from other sciences and technologies, in close connection with institutions generators of development, competitiveness and more sustainable solutions. In order to base the construction of this bachelor degree proposal, the MD of the Higher Institute of Engineering of Lisbon (ISEL) carried out a careful study about the existing applied mathematics degrees, not only in Portugal but also abroad. This study proved to be particularly enlightening in identifying training combinations not yet explored by national higher education institutions, in which it was still difficult to recognize any connection to institutions and business organizations. Some inspiring degrees were: Industrial Mathematics at Bremen University in Germany, and Mathematics with specialisation in Statistics, Economatics or Mathematical Engineering at Autonomous University of Barcelona in Spain. LMATE was inspired by these degrees with a strong mathematical and computer base, different curricular units (CU) linked to industrial mathematics, modeling and management. However, although these courses have a final degree work with significant weight, they have no connection to companies during the degree like LMATE. Aware of the pertinence and the need to strengthen the relationship between the academy and the community (Feron, Poinsotte and Jossic 2022) the MD established multiple contacts and promoted several work meetings with heads of different companies and entities, many of which have an undeniable economic and social role. These contacts, all of which were well received by enterprises and institutions, resulted not only in a crucial contribution to the structuring of the bachelor degree, integrating fundamental contents into the syllabus of the CU, but also in triggering their participation in seminars and workshops integrated into the degree, as well as the offer of internships, resulted in a unique training offer and an even greater alliance between ISEL and the scientific and technological community. LMATE presents three fundamental differences in relation to other applied mathematics degrees existing in Portugal: 1) It was constructed in the opposite way to the usual, in the sense that the subjects that the partner institutions considered to be relevant to later apply in solving their problems were identified first and after were inserted these themes in the syllabus of the CU. That influenced also which CU that should be part of the curriculum. Instead of the degree being designed solely by the academy; 2) It has in its curricular plan optional CU from the various areas of engineering at ISEL, in order to familiarize students with important areas that they will integrate when they go to do internships at partner entities; 3) It is the only undergraduate degree in applied mathematics that has an internship integrated into its 3-year curriculum structure.

The structure of the proposed degree thus resulted in innovative, forceful and flexible training in the Portuguese reality, both in terms of differentiation in relation to the existing offers in higher education, and in the needs of companies and entities in the country.

3 LMATE

3.1 Bachelor Degree objectives

LMATE intends to develop and apply, in a multidisciplinary context, advanced mathematical and computational methods in the formulation, resolution and interpretation of relevant problems in different domains, in particular real problems raised by the several branches and sectors of activity (many of them improving sustainability). In this sense, LMATE is aimed by candidates with varied profiles and interests, aspiring to provide its students with a considerable set of scientific and professional skills.

The set of CU that make up LMATE, aims to offer its students solid knowledge that will allow them an early and successful entry into the job market, or, if they prefer, the continuation of their studies in masters in a diverse set of areas.

The LMATE curricular flexibility seeks to be made up of current, appealing and multi-disciplinary options, in areas such as mathematics, engineering, physics and management, where the greatest possible advantage is taken of the training offers of other ISEL departments. Throughout the training course, MD has promoted seminars/workshops, carried out by professionals from partner entities, so that LMATE students become familiar with research projects since the first curricular year. The biggest challenges presented by the partner entities are for the internship themes, and the smaller ones will be, whenever possible, object of study in the curricular units designed for this purpose.

The bachelor degree culminates in an internship at a partner entity or in a project that provides:

- obtaining knowledge and experiences advocated by the articulation between theory and practice;
- autonomy in the acquisition of scientific knowledge necessary to carry out the proposed tasks;
- the development of relevant and necessary skills, habits and attitudes for the acquisition of professional skills;
- a closer relationship between ISEL and the community.

By contemplating the elaboration of protocols with partner entities, LMATE favors the integration of graduates in the labor market.

3.2 Students admission

Initially, were assigned 30 vacancies to LMATE for the national competition for access to higher education (CNAES). In 2018, due to national politicies it became 28 vacancies.

Since its first year of operation, LMATE has had all of its vacancies filled in the first phase of the CNAES. The few registrations not carried out in this phase, automatically transferred to the second phase, were also completely filled out. Between 30% and 40% of the placed candidates choose LMATE as their first option.

Some statistics about students who entered LMATE can be consulted in Table 1:

Table 1. Statistics of candidates who joined LMATE through CNAES

Year	Min.Ph.1	Max.Ph.1	Aver.Ph.1	Plac.Ph.1	Min.Ph.2	Max.Ph.2	Aver.Ph.2	Plac.Ph.2
16/17	11.84	14.00	12.66	30	13.44	13.96	13.70	7
17/18	13.20	15.66	13.80	30	14.68	16.26	14.96	3
18/19	12.80	15.98	13.76	30	13.98	15.50	14.57	6
19/20	13.34	15.66	14.17	28	14.34	15.04	14.69	6
20/21	13.36	16.06	14.24	28	14.74	15.96	15.25	2
21/22	12.72	15.54	13.86	28	14.42	15.42	14.70	6
22/23	14.22	17.20	15.21	29	15.46	16.54	16.04	4

LMATE has recurrently had a demand far greater than the offer of vacancies in any of CNAES phases. Regarding the *1^s* phase, Table 2 has some relevant data.

Table 2. Number of 1st phase LMATE candidates, vacancies and demand rate

Lective year	Number of candidates	Number of vacancies	Demand rate
2016/2017	70	30	233%
2017/2018	173	30	577%
2018/2019	240	30	800%
2019/2020	165	28	660%
2020/2021	161	28	772%
2021/2022	109	28	389%
2022/2023	211	29	728%

3.3 Curricular Structure

The curriculum plan proposed for LMATE was distinguished in several aspects of the structures offered in different institutions with training programs in the same area of knowledge in Portugal. The offer of CU in the first year of the study cycle is varied (see Fig.1), covering some fundamental topics for the student to acquire the intended base skills. The diversification of competences is achieved by the progressive offering of a wide range of options, in which the direct contact with the several scientific areas of ISEL is privileged and which will translate into easier adaptation to the interdisciplinarity required by real problems. This way, the student has the possibility of organizing his study plan with predominance in application in one of the engineering areas of his interest. The internship/project (see Fig.2), which may extend to partial regime throughout the 3rd year curriculum (modality 1) or focus on the 2nd semester of the 3rd year (modality 2), will materialize the connection to concrete problems of the business world, consistent with the nature of the study plan. The main areas of LMATE study are: mathematics, statistics, operational research, optimization, numerical analysis, modeling, simulation and programming. LMATE curriculum plan includes 19 mandatory and 7 optional CU. Between the mandatories CU: 4 are in pure mathematics; 1 in numerical analysis that allow them to learn alternative methodologies to solve insoluble mathematical problems analytically, and other 2 more advanced, mixing analytics and numerical analysys; 1 of Physics, useful in formulate, modelate and solve some kind of specific problems; 4 are in statistics, which enables students to acquire strong training in this necessary area, much requested later in internships and in professional life; 2 in operational investigation and optimization, much useful in solving real labor market problems, allowing to assist decision-making; 1 in Management that allows students to evaluate the economic impact of the new methodologies they apply, and finally, 1 of Modeling where real problems are solved as preparation for the internship. In addition to math options (like Quality and Reliability Control, Bayesian Statistics or Operational Research Complements), students have annually a vast list of other optative CU in physics, engineering and soft skills; namely Machine Learning, Artifitial Intelligence, Data Bases, General Chemistry, Electricity Networks and Telecommunications, and Marketing and Interpersonal Communication.The dynamic structure of the LMATE curriculum plane should be emphasized, in the sense that the CU programs changes, given the pedagogical experience that has been gaining with the teaching development, aided by the contribution of partner entities regarding the performance of students in the internships. The contribution of LMATE partners was very important in creating the bachelor degree, but it remains crucial for its update, so that it will increasingly meet the needs of the labor market that becomes extremely demanding.

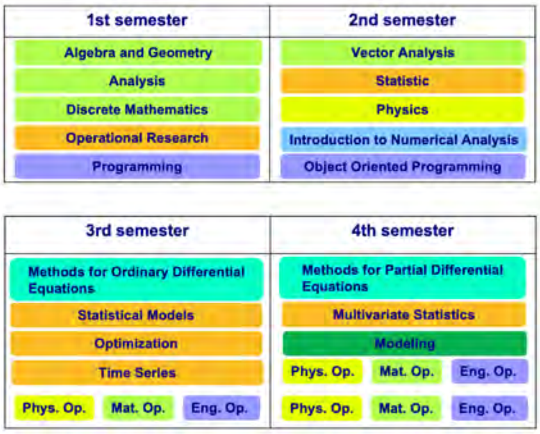

Fig. 1. LMATE Curriculum – 1st and 2ndyears

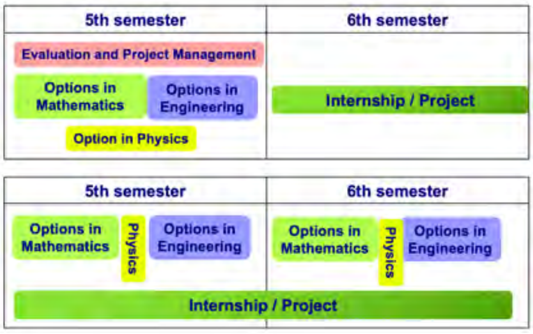

Fig. 2. LMATE Curriculum – 3rd year

3.4 Teaching and Evaluation Methodologies

In general, the several CU work on a theoretical-practical basis, with some working in a computer lab. All subjects have support lessons beyond class hours, and in addition, the teachers are always available to answer questions, existing a great proximity between students and professors. The CU assessment comprises a theoretical part by tests or by exam, but always has a practical component consisting of one or more individual or group assignments. In most cases, practical assignments are submitted to an oral presentation and discussion, which allows validating the learning outcomes and providing public speaking skills for students future professional life. The strong acceptance of the works carried out by the students in the internship by the partner entities of LMATE, is a strong indicator of the adequacy of the learning results obtained and consolidated throughout the degree.

3.5 Coordinating Committee

Since the beginning of operations, LMATE has had its coordinating committee (CCLMATE) divided into two parts: one academic (as usual) and the other linked to partner entities, responsible by: 1) attracting new entities; 2) determining enterprises mathematical problems for internships and for exercises in classes; 3) booking partner entities workshops/seminars; 4) organizing events involving partners; 5) listening to the opinion of these entities regarding: a) the performance of students in internships, b) students knowledge and c) possible suggestions for the insertion of new syllabus contents in the CU of the degree. This way of operating LMATE has proved to be extremely versatile and profitable.

3.6 Partner Entities

The main added value of LMATE is undoubtedly its partnership with enterprises and institutions, allowing an enriching exchange between academia and the job market, beneficial for both parties. At the creation of LMATE, there were already a dozen partners in several sectors. This number has been growing, so that currently LMATE has thirty-seven protocols signed with partner entities, which essentially cover three types of collaboration: 1) participation in seminars; 2) offer of curricular internships to LMATE students and 3) consultancy projects carried out by ISEL MD professors. These partners cover a wide range of areas, namely, **energy**: EDP, GALP, REN; logistics/transport: Transportes Paulo Duarte, Wurth, A-To-Be (Brisa Inovação), Delta; **metalworking/equipment industry**: Sandometal, Exide; research: CDRSP(IPLeiria), LNEC, IPMA; **pharmaceutical/health industry**: Hovione, Grupo Lusíadas, Alliance Healthcare; **services**: Águas do Tejo Atlântico, Câmara Municipal de Lisboa, Infraestruturas de Portugal, CTT, Tecmic, Secretaria Geral da Economia e Mar, Wikiservice, Carclasse, Antúrio, ISX4 Analytics, Jerónimo Martins; **insurance**: Allianz; **consulting/investment**: Closer, Milestone; Bring Global, Dolat Capital; **telecommunications**: Celfinet, Solvit; mold industry: Iberomoldes, Centimfe; **lighting**: Arquiled; media: Media Capital.

3.7 Internships and Projects

The number of LMATE internships and projects has been growing: 5 in 2018/19, 14 internships and an anual project in 2019/20, 18 internships and 3 projects in 2020/21, 27 internships and 2 projects in 2021/22. In 2022/23, as a result of the pandemic, the number of internships had decrease to 14 and 1 project, accompanying the decrease of students in higher education. As examples, some titles of internship reports are listed, namely: Wind Power Forecast with Machine Learning (REN), Optimization of the allocation of transport services (Tecmic), Use of machine learning techniques in predicting the capacity of LTE cells (Celfinet), Estimate Fishing Effort and Predict Operating Gear (IPMA) and Empirical Statistical

Modeling of Equipment with Monitoring of Lubricants in Service for Proactive Maintenance (Galp).

3.8 Path of students who completed the LMATE degree

Currently, there are about 80 students enrolled, 62% male and 38% female. So far LMATE has 67 graduates. A follow-up study was carried out on the path of students who had already completed the degree, contacting them by phone or by email. Many of the LMATE finalists go on to master's degrees, most of them right after finishing the LMATE. Others enter the labor market straight away. According to the study, it has ben concluded that: 1) students who are attending or have already completed a master's degree considered themselves well prepared by LMATE for these masters. Many of the topics to be addressed in these masters have already been covered in LMATE; 2) students consider that the computational tools used in LMATE are an enormous asset in the master's degrees, in addition to helping them to carry out their functions in internships at LMATE's partner entities, as well as in their performance in enterprises where they are currently working; 3) students who are already working consider that the internship was very important for them to enter the job market. Also according to the same study, around 30 former LMATE students are already working in several areas of applied mathematics and computing, namely in consulting, banking, insurance and software companies.

4 FINAL CONSIDERATIONS

LMATE has been successful since its creation in 2016, once it has always filled its vacancies and has a dropout rate around 10%, as others ISEL bachelor degrees. Its students recognize the differences that distinguish this applied mathematics degree from others on the market, due to: 1) its solid teaching in mathematics, but at the same time practical; 2) the use of several software; 3) its dynamic construction aided by partner entities; 4) the support and availability of teachers; 5) internships integrated into the curriculum at well-known enterprises and institutions, which bring them closer together and facilitate their entry into the job market. LMATE finalists have enrolled in master's degrees at ISEL and at other important higher education institutions, and the knowledge acquired at LMATE has proven to be quite adequate for carrying out these masters degrees. Half of the students who finished LMATE (some are still doing their master's) are already in the job market applying their mathematical knowledge. The others are mostly carrying out the master's degree exclusively.The creation of LMATE was an innovation, attracting students who otherwise would not come to an engineering school, allowing a fruitful exchange of knowledge and experiences between these students and engineering students who share some UC and live together at the school. LMATE has conquered its own space in the higher education of Applied Mathematics in Portugal, greatly contributing to this, the performance of its students in internships at partner entities who recognized their work. Since LMATE students, as workers, contribute to the optimal solutions of many processes/resources, they are improving the sustainability of our world.

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ENG+ | ETHICS FOR SUSTAINABLE DEVELOPMENT IN ENGINEERING PROGRAMMES

A PRAXIS REPORT OF TU BERLIN'S THINK TANK *TECHNOLOGY REFLECTION*

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***Keywords**: Ethics, Integration, Reflection, engineering programme transformation, curriculum transformation*

ABSTRACT

Many technical universities alike, TU Berlin is in a future-oriented process of programme transformation to invite a holistic perspective on technology which includes critical thinking and ethical reflection. To this end, TU Berlin recently issued a general study guideline calling for an orientation of all programmes toward sustainable development. Accordingly, students should know about the historical, social and cultural contexts of science and technology and learn to reflect on the ethical consequences of their actions. Together with training in good scientific practice, this content should comprise 12 ECTS in each respective BA and MA programme. With only minor integration of this content in the current curricula to date, this transformation presents a significant challenge since courses need to be realigned as well as replaced. To find an answer, TU Berlin’s engineering faculty initiated a think tank in spring 2022, bringing together students, teachers and administration to search for ways of integrating ethics as well as science reflection and technology reflection to foster sustainable development. In our contribution we present a first outcome, namely the integration framework ENG+ for programme design which allows for the incorporation of ethics and strengthening of core values such as diversity, sustainability, and good scientific practice. In the ENG+ framework, we introduce the strategies of advancing and complementing as well as six corresponding measures for integration – emphasising, empowering, embedding, enabling, enriching, and encountering. We explain how they jointly contribute to the overarching ENG+ concept which brings together ethical reflection and sustainable development.

1 INTRODUCTION

TU Berlin's new General Study and Examination regulation requires that at least 12 credit points (in the following addressed as ECTS) need to be devoted to ethics, science reflection and technology reflection in every degree programme to foster sustainable development. Hence, the key question is: how can these topics be implemented in the TU Berlin engineering programmes? As the structure of the programme design is fixed due to the required 180 ECTS for Bachelor's and 120 ECTS for Master's degrees, a redesign is needed. The TU Berlin has approximately 35,000 students, of whom 5,454 are enrolled at the *Faculty of Mechanical Engineering and Transport Systems*. This requires an enormous transformation at our institution, which will take a lot of time and resources. Furthermore, it requires a fundamental change in the approach to teaching philosophy as well as to engineering. Since the TU Berlin has thus far lacked experience in systematically implementing ethics, sustainability, and gender and diversity perspectives in study programmes, the faculty initiated the *Think Tank Technology Reflection* in spring 2022 where students, teachers and administration come together in monthly meetings. As members of the think tank, we want to present the ENG+ framework for programme transformation as a first result from the think tank process.

Regarding the overarching aim of the transformation, we want to point out three aspects which specify the unique starting point of our engineering faculty, in terms of its opportunities and challenges. Firstly, as engineers, we are already sustainable in terms of cost and material reduction. Hence, there is a basic understanding of sustainability and approaches at hand which can be built upon. Secondly, due to the engineering departments of our institution (e.g. transport, product development, machine design, human factors) we have a good thematic foundation for human-centred design processes which can be extended to include broader societal and ethical reflections. Thirdly, there is a strong emphasis on making and doing, which comes with a lack of discussion culture in engineering education. The latter, however, is essential for implementing ethics, science and technology reflection. Thus the appreciation and training of discussion and reflection represents a major challenge when it comes to curriculum transformation.

Our paper starts with an overview of the main challenges reported in the literature (Sec. 2). How these will be tackled by the strategies and measures of the ENG+ framework is the topic of Section 3. Section 4 shares the challenges of the ongoing process. We conclude with an outlook of the next milestones.

2 CHALLENGES OF INTEGRATING ETHICS, SCIENCE AND TECHNOLOGY REFLECTION INTO ENGINEERING PROGRAMMES

Since the 1980s the necessity of ethics education and the importance of strengthening reflection competencies has been consistently highlighted in the literature of engineering education (Grunwald 1999; Mitcham and Englehardt 2019; Sætra and Danaher 2022; Fiesler, Garrett, and Beard 2020). Nevertheless, advancement has been slow, and "the question of the integration of the ideal of engineering education for ethics has been largely ignored" by academic research (Martin, Conlon, and Bowe 2021, 24). Although there are good examples of the integration of ethical reflection into engineering programs, such as programmes at TU Twente and TU Delft (van de Poel and Smuga-Fries 2015; Doorn 2021), there are still challenges to overcome.

In the literature of engineering ethics education, two main challenges have been reported. Firstly, teachers often struggle to understand and ensure alignment among the variety of theoretical frameworks, learning objectives, instructional activities, and assessment methods. There are numerous interrelated learning objectives, but no consensus in the literature as to which strategies are most effective in achieving them or which objectives should be prioritized (Martin, Conlon, and Bowe 2021). This means that teachers find it particularly difficult to formulate ethical learning objectives for their courses or modules (ibid.) – especially because of a lack of familiarity with ethical issues and methods. This raises the problem of deriving appropriate didactic as well as pedagogical content and methods to connect ethical issues to technical ones. To address this issue, co-teaching activities can be implemented, in which engineers work together with philosophers and social scientists to integrate socially relevant aspects into technical contexts and to show that ethics and technical thinking go hand in hand. The approach can be improved by integrating ethical mini-modules into existing modules, so that students become habituated to reflecting ethically. In this way, students can learn about a variety of concrete ethical issues and problems in their field.[1] Co-teaching also provides another additional advantage, as "interdisciplinary ethics learning provides a better basis than disciplinary ethics learning" (Mitcham and Englehardt 2019, 1756).

Secondly, institutional framework conditions and a lack of support from the administration represent another major obstacle. The challenges listed above are further compounded by institutional constraints: the prominence given to ethics in the curriculum is critical to conveying the message to students that ethics is not a peripheral issue in engineering, but an essential aspect of their profession (Mitcham and Englehardt 2019; Fiesler, Garrett, and Beard 2020; Martin, Conlon, and Bowe 2021). This is why the "top-down support to secure appropriate embedding in the university" cannot be stressed enough (Mitcham and Englehardt 2019, 1756). To ensure appropriate embedding in the university, support is needed from the administration. As it is clearly an important, and certainly open, question how to make room for new content in full curricula, thus a coherent and focused overall strategy for a unified curriculum is needed. In order to make societally relevant aspects central to education, having a coordinated institutional response is a central requirement (cf. Martin, Conlon, and Bowe 2021). Support from the institution is also needed to implement support services such as professional training, joint

[1] A good example of an integrative, overarching approach can be seen at the TU Twente and TU Delft ("RESTS REflection on Science Technology and Society (RESTS)" n.d.; van de Poel and Smuga-Fries 2015; Doorn 2021).

development of course content or teaching (for example, in the sense of co-teaching), or mentoring and networking opportunities (cf. Mitcham and Englehardt 2019). Prioritization of an implementation strategy is the only way to ensure systematic implementation of a unified curriculum.

A key learning from these reports is that a coherent and targeted strategy at the institutional level is needed to implement ethics systematically in engineering programmes. As a first step, this requires an overarching concept at the programme level which breaks down to the second step of a curriculum redesign at the course level with appropriate learning goals. To set such goals, working together with philosophers and social scientists as well as program committees is essential for connecting ethical reflection to the discipline-specific content of the programs. Additionally, further support from the institution is necessary regarding training courses to help teachers learn about ethically relevant issues in their discipline, support them in formulating ethical learning goals, and develop teaching material for their courses.

3 ENG+ FRAMEWORK: INTEGRATING ETHICS, SCIENCE REFLECTION AND TECHNOLOGY REFLECTION INTO ENGINEERING PROGRAMMES

3.1 Background

A starting point for the transformation process at TU Berlin was a long-range, university-wide vision for teaching which was adopted in 2018. It includes educational goals and combines academic education with personal development:

> *The mission statement for teaching […] forms the basis for all regulations, rules and strategies that determine teaching at the TU Berlin. It must be reflected in all study and examination regulations, in the curricula and in quality management for studies and teaching. […] Our teaching enables students to face technological change and its social impact with creative ability, a sense of responsibility and high professional qualifications. (Technische Universität Berlin 2018, 5-6)*

This mission statement has been transformed into a binding requirement for all Bachelor's and Master's programmes by the new General Study and Examination regulation (AllgStuPO):

> *[1]In the study programmes, the rules of good scientific practice are taught at the earliest possible stage and continuously trained. [2]Students learn to place knowledge and action in an overarching historical, social and cultural context and to consider ethical consequences of action in order to be able to contribute to sustainable development. [3]It is to be ensured that all students have completed relevant study content amounting to at least 12 ECTS by the time they graduate. (Technische Universität Berlin 2021, §44, 3)*

To respond to the new AllgStuPO, members of the *Faculty of Transport and Mechanical Engineering* launched the think tank at an internal faculty meeting in spring 2022. Its aim is to develop an overarching strategy for integrating ethics, science reflection and technology reflection. It should serve as a vision for curriculum redesign and, as a follow-up step, the (re)design of courses. The think tank's monthly hybrid meetings brought together students, teaching and administrative staff, as well as two women's representatives. Since the think tank raised interest also from other faculties as well as the university's central administration, we were able to draw on perspectives across the university.

3.2 ENG+ Framework: Strategies and Measures

As a first result of the think tank, we want to present an overarching heuristic for integrating ethics as well as science reflection and technology reflection to foster sustainable development. Methodologically, the think tank started with a literature review of the key learnings and challenges when trying to integrate ethics into engineering education (see section 2). A coherent and targeted strategy at the institutional level was then identified as the central goal. Subsequently, a conceptual analysis of possible ways to connect ethical reflection to the discipline-specific content of the programs was conducted. As a result, the integration framework ENG+ offers different ways of implementing these topics in programme design. Contextualizing engineering problems allows students to see their broader societal and environmental impact, to understand the interrelation between technology and society, and to grasp potential ethical risks in emerging technologies. From a traditional (disciplinary) point of view, this endeavor is of a deeply interdisciplinary nature, as it brings to the engineering curriculum knowledge and competencies rooted in philosophy, humanities, and social sciences. However, ENG+ is less about including additional disciplinary viewpoints, but rather introducing students to holistic thinking and enabling them to experience the intrinsic complexity of technology.

To arrive at an integrated programme design, ENG+ draws on two major strategies, advancing and complementing, which need to go hand in hand (see fig. 1).

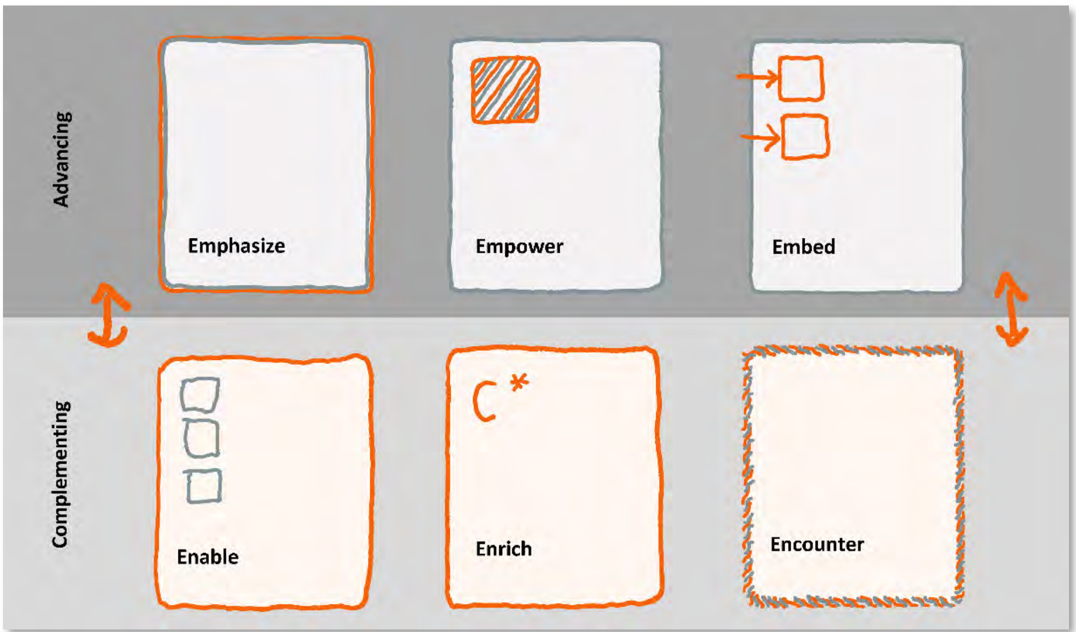

Fig. 1. ENG+ framework to integrate ethics, science reflection and technology reflection into engineering programmes. Graphics: S. Ammon 2023

Advancing aims at the further development of existing STEM courses to show the relevance of ethics and reflection for engineers, as well as the connection to STEM topics. Advice, training and targeted support for STEM teachers will play a key role here. Advancing comprises the following measures:

- **Emphasize**: further development of existing STEM courses that have already integrated ethics, science reflection and/ or technology reflection and establish the contribution of these areas to sustainable development within the framework of the subject of the course. Targeted emphasis will make this orientation more visible and strengthen it.
- **Empower**: further development of existing STEM courses that have not yet integrated ethics, science and/ or technology reflection. Through targeted guidance and training, teachers are empowered to integrate ethics, science and/or technology reflection and to establish the contribution of these areas to sustainable development within the context of the course topic.
- **Embed**: further development of existing STEM courses that draw on the expertise of ethics, humanities and/ or social science experts to embed ethics, science reflection and/or technology reflection. For this purpose, mini-modules (e.g., 2-6 h per week) are integrated into the existing course in order to incorporate questions of ethics, science reflection and/or technology reflection directly into the overarching topic of the course.

Complementing furthers the development of new courses in the area of ethics, science reflection and technology reflection. They should comprise topics such as research ethics, professional ethics, technology ethics, environmental ethics, technology assessment, history of science and technology, or science and technology studies. It will be essential to tailor the content of these courses to topics of the respective STEM disciplines. We recommend that interdisciplinary co-teaching be given a high priority. Complementing comprises the following measures:

- **Enable**: A foundational course that introduces basic ethical concepts and trains ethical reflection practice. The added value of ethical knowledge and ethical competencies for sustainable development is to be made tangible by directly linking ethical issues to topics in the STEM fields. The contextualization of technology and science and their critical reflection play an important role.
- **Enrich**: In-depth courses in the field of (applied) ethics, science reflection and technology reflection. Students can earn certificates, which certify a focus of study. The Faculty of Mechanical Engineering and Transport Systems offers in-house certificates such as the Berlin Ethics Certificate (see Ammon et al. 2022) and the Sustainability Certificate.
- **Encounter**: Interdisciplinarity can be experienced through collaborative teaching and learning in diverse settings by teachers from STEM areas and humanities or social sciences. Differing disciplinary cultures and perspectives can be experienced, along with the relevance of interdisciplinary cooperation. The collaborating teacher acts as a role model.

For a successful programme transformation, the strategies of advancing and complementing need to resonate with each other. That means a complementary curriculum design, mutual references of the courses, as well as an overall vision which draws on sustainable development need to come together. This also implies a *cultural change* which strengthens a culture of togetherness and encourages cooperative forms of teaching and learning. An appreciation of diversity, a non-discriminatory environment, the ability to change perspectives and a constructive approach to divergent opinions as well as to inter- and transdisciplinary are all important elements of this strategy. Teachers serve as key role models in this cultural change.

ENG+ as an overarching vision for programme design ensures that the different measures interrelate with each other. It also shows that it is not required that all courses address the topics of ethics, technology reflection and science reflection to the same extent. The integration of ethics, science reflection and technology reflection is more than the sum of different measures; thus it is the overall effect that counts.

4 HURDLES IN IMPLEMENTING THE ENG+ FRAMEWORK

Since the new General Study and Examination regulation leaves open how the 12 ECTS are covered in the degree programmes, it is up to the programme directors to decide. For the implementation of the ENG+ framework, we suggest a pragmatic approach in which 6 ECTS are anchored in the engineering programme by advancing and another 6 ECTS by complementing measures.

For **complementing**, a best practice example can be found in the physical engineering programme which has introduced an elective area for students to choose among courses on ethics, sustainability, as well as gender and diversity. However, choosing e.g. a course on sustainability would not necessarily imply that students are taught ethics. This leaves open the question of how it can be ensured that every student learns about basic concepts and approaches of applied ethics.

Another obstacle is that traditional, conservative ways of thinking that can cause difficulties in creating space for new topics in the curriculum. Teachers who see the training of technical competences as the sole goal of engineering education may be resistant and underestimate the relevance of critical reflection and the ability to act sustainably and responsibly.

When it comes to **advancing**, a high level of topics surrounding ethics, science reflection and technology reflection is desirable. However, not every course will be suitable to cover these issues in a meaningful way. For courses like linear algebra or other basic mathematical subjects, an integration might seem rather forced and far-fetched. The advancing strategy also comes with measuring challenges for examination administration. Once the topics are dealt with in an integrative way, how can the 6 ECTS be detected? For example, in a 6 ECTS course which deals to some extent with issues of gender and diversity, how many transformation points does it cover? Should a course which deals with the design of wind turbines be counted in full towards covering sustainability, simply because wind turbines are counted as renewable energy? There are currently no sensible answer to such questions.

In addition, the strategy of advancing requires that teachers be empowered to integrate ethical issues into their technical courses. This requires expert advice and support or training for teachers. Probably the biggest obstacle to the implementation of this strategy is funding, as well as the creation of free time in everyday university teaching. The use of initiatives to promote innovation in teaching, as well as centralized university training, can provide at least some support. Also, teachers must be encouraged to further develop themselves and their courses in this direction. This requires suitable incentive systems.

At the same time, however, this can also contribute to the cultural change needed to support the overall transformation process. Raising awareness among faculty members through structural measures and promoting formats for exchange and networking between teachers can contribute to a culture of togetherness. Collaborative forms of teaching, which could contribute to this cultural change, currently face administrative obstacles. For example, the crediting of co-teaching courses cannot be taken into account in teaching performance according to effort. Existing calculation models should be reviewed to ensure that teachers have the freedom they need to develop themselves and their courses. It is clear that the transformation process needs to be supported by overarching measures, which still need to be identified.

5 OUTLOOK

After having developed the ENG+ framework, the next step will be its implementation and testing within a prototypical engineering programme. To this end, a process of quality assurance needs to be developed, which includes reporting to and feedback from the executive board. The process of redesigning programmes as described above takes time, a lot of resources and commitment. Thus it is important to raise awareness and empower teachers to integrate ethical issues into their courses. It is also necessary to have administrative and professional support for the change process. To this end, we want to use the ongoing think tank to encourage exchange and networking among faculty members, as well as to facilitate formats such as workshops, peer-to-peer consultations, mutual shadowing, expert support and learning from other institutions.

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Multicultural Online Collaborative Learning: Students’ Engagement in Design Thinking Framework

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ABSTRACT

This paper presents a collaborative learning course in which students from four universities in different Asian countries work in mixed teams to learn how to develop user-centered products and solve problems in a hands-on way using the Design Thinking framework. For the past three years, the courses were conducted entirely online. Cooperation and collaboration among diverse people from different backgrounds are essential to solving the social problems facing the world today. Like many universities, we have been actively sending our students abroad to provide opportunities to experience diverse cultures and values, but the pandemic has made it very difficult to travel abroad for the past three years, forcing universities to shift from face-to-face classes to online classes. The pandemic has made it extremely difficult to travel abroad for the past three years, and universities have been forced to shift from face-to-face to online classes. During this time, four Asian universities, to which the authors belong, have jointly launched an online problem-solving collaborative learning course aimed at supporting students to "No one will be left behind," as stated in the SDGs.The structure of the course, profiles of participating students, improvements to the course, student evaluations, and challenges found are described.

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1 INTRODUCTION

1.1 Context and Motivation

The year 2020 forced education into chaos caused by the Pandemic. University students in Asia were no exception. Learning and teaching platforms shifted to online, and faculty and students who viewed the face-to-face teaching/learning format as self-evident were in dire straits. Leaving universities as a temporary evacuation made many international students challenging to come back due to travel constraints. Faculty staff worked hard to find sustainable ways to include all the students worldwide to keep them connected to the learning process.

Collaboration skills, English language skills, and cross-cultural understanding are necessary for engineering students to work together in the future to solve social problems that transcend national borders. Japan’s Ministry of Economy, Trade and Industry expressed the expectation to foster students with good social skills and expertise. It introduced the requirement for competitive workers in ‘Fundamental competencies for working persons in the era of 100 years of life and recurrent education.’ in 2018. (METI 2018) ASEAN countries are no exception in developing human resources with 21st-century skills. (UNICEF 2019) Thus, the authors were on the same page in building a program to meet our shared goals to help students improve problem-solving skills, and communication skills, especially in English language collaboration skills, and cross-cultural understanding.

A pilot project started online in 2020, “Global Collaborative Learning: Design Thinking PBL(GCL-DT-PBL)” for engineering students between a Japanese and a Malaysian university, was a countermeasure for sustainable education against the Pandemic devastated teaching and learning environment. Then in 2021, two other ASEAN universities joined the loop, and *GCL-DT-PBL* became a full-fledged 4-year project, inviting many more students from diverse cultures. The following sections will describe the structure and implementation of the program, the analysis of student engagement relevant to the program goals, and the findings.

1.2 Program Structure and Implementation

Many researchers have found the effectiveness of PBL as a means of learning as it is student-centered and enhances real-world problem-solving skills, higher-order thinking, and self-directed learning compared to the classic learning approaches. (Du et al. 2009)

Design Thinking is widely applied in many fields, including architecture and urban planning (Rowe 1986), product design, businesses, and education. (Brown 2008) (Kelley and Kelley 2013) Multicultural PBL was integrated into the Design Thinking framework as the program's instructional design based on our common goals. (*Table 1.*)

Table 1. Global Online Collaborative Learning: Design Thinking PBL (GCL-DT-PBL)

Year	Participants	Universities	Duration	Platform	Theme
2020	20	2	7 days (14hrs)	Online	Innovation in COVID-19 Crisis
2021	36	4	6 days (30hrs)	Online	Innovate UTM Campus Cafeteria
2022	31	4	6 days (30hrs)	Online	Innovate UTM Campus Cafeteria

Fig. 1. Design Thinking Process
(The first author created using Canva)

Fig. 1 Shows five steps design thinking model applied and is based on a guideline Stanford Design Thinking of GCL-DT-PBL. Test in Stage 5 was not conducted in 2020 and 2021 due to the constraint caused by the Pandemic but held face-to-face in 2022 in Malaysia with participants from three ASEAN universities. Japanese university was unable to make it because of travel constraints.

2 METHODOLOGY

Data Collection and analytical method

The Google Forms questionnaire was sent to the participants after each program. Responses were collected, and the content was analyzed using text mining software KHcoder. (Higuchi 2016)(Higuchi 2017) Content analysis is an analysis of the content of the communication. Analyzing the written content, especially in the responses to the questions collected after the program is over, helps understand the engagement of the participating students. Text mining is an analytical method to capture potentially useful information from document data. *Table 2.* shows the elemental attribute composition of the data used in the analysis.

Table 2. Elemental attribute composition of the data used

Year	Response	Participants	Number of universities
2020	16	16	2
2021	36	36	4
2022	9	31	4

The focus of the analysis was to explore the students' engagement. The response items text analyzed include expectations for the program, how the programs met the initial expectations, the best part, and the challenges the participants met.

One helpful method for examining text mining results is to read co-occurrence networks applied in our study. A co-occurrence network is a graphical representation of the distance between extracted words. Larger circles connect words with high frequency, and darker lines connect words close to each other. The co-occurrence network allows us to see how frequently occurring words are combined. The context in which the term was used can be deciphered by returning to the description's original text.

3 RESULTS AND FINDINGS

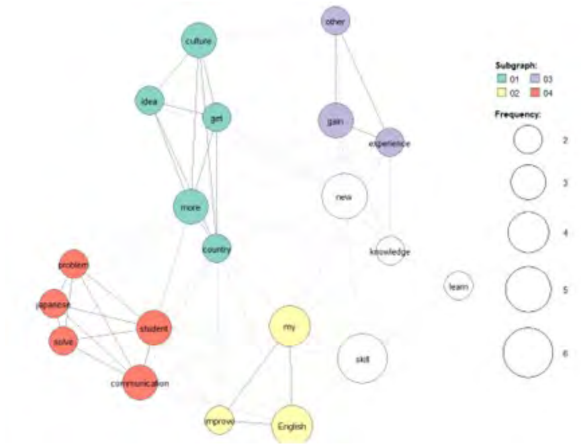


Fig.2 2020 Initial Expectation

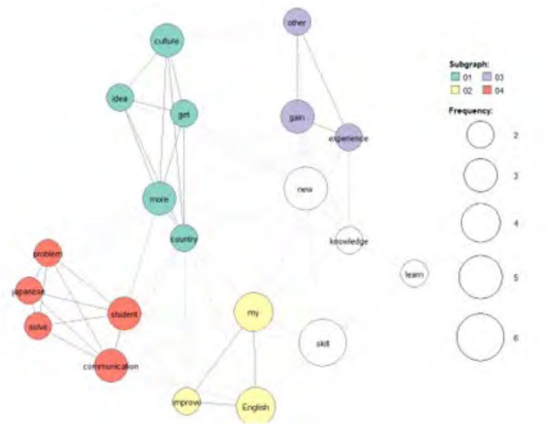


Fig.3 2020 Consistency with Expectation

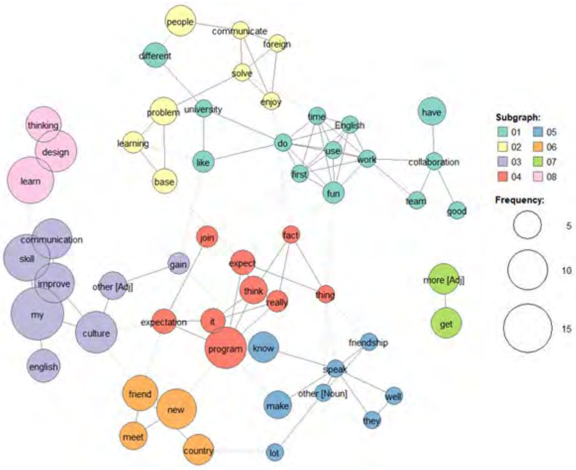


Fig.4 2021 Initial Expectation

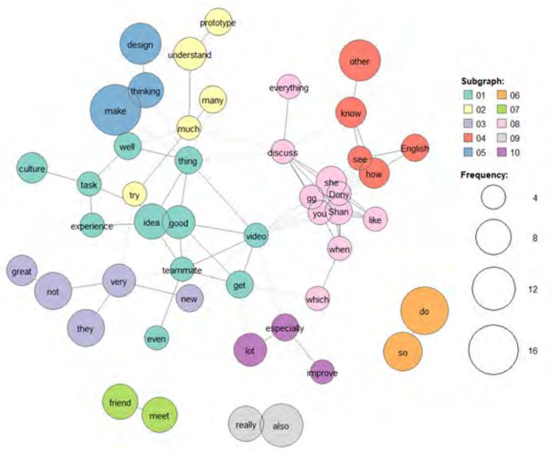
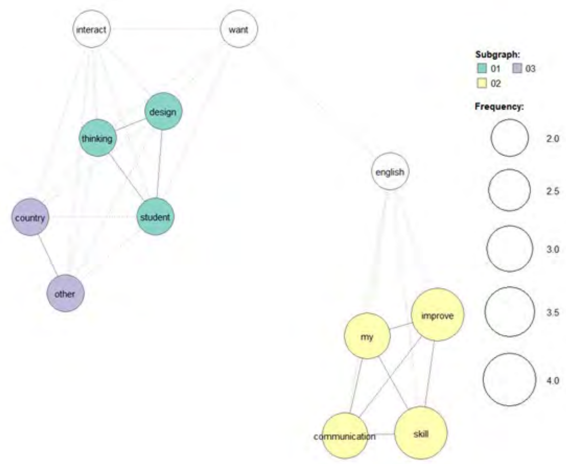


Fig.5 2021 Consistency with Expectation



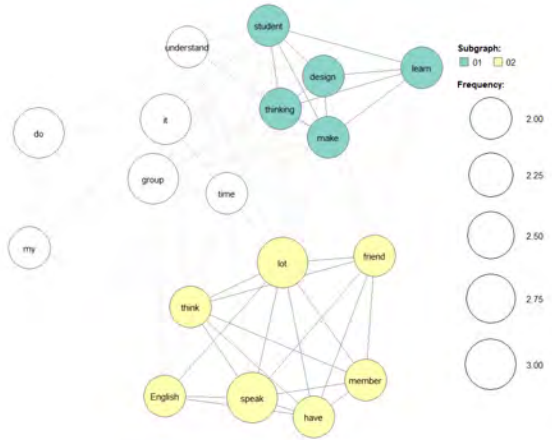


Fig.6 2022　Initial Expectation　　*Fig.7　2022 Consistency with Expectation*

The notably common initial expectations for the three programs in 2020-2022 were: 1) To learn about other cultures and work with new friends and 2) To improve communication skills in English. Few expressed the expectation for learning Design Thinking driven problem-solving. However, the responses to the question about whether the program met expectations were different. Among the familiar words that strongly link the three programs is <u>design</u>-<u>thinking</u>-<u>new</u>-<u>experience</u>-<u>make</u>. This suggests that problem-solving and prototyping in a design thinking framework was a fresh and meaningful experience for the participants. Below are the textual statements extracted from the KWIC concordance showing how the aforementioned linked word groups appear.

- *I 've done <u>new</u> and challenging things from this program .*
- *I still gain a lot of knowledge such as about <u>design</u> <u>thinking</u> , <u>new</u> skills on how to <u>make</u> a prototype mobile apps -LRB- which actually was asked by a company that is currently interviewing me for my internship -RRB- and also <u>new</u> <u>experience</u> .*
- *we must <u>make</u> a project and that 's it really great <u>experience</u>*
- *I have found a <u>new</u> achievement for myself during this program*

KWIC concordance is an abbreviation for keywords in context. It is possible to see which words that appear at the top of the list of extracted terms are used in the sentence. KWIC concordance lets us see how frequently words are used in a sentence.

Regarding the degree of conformity with the original expectations, all but one of the respondents in all three years indicated that the program met their initial expectations. The reason statements of the participant whose expectation was not matched show that the greatest expectation for the program was to improve their English proficiency, as one stated, "My proficiency level still remains the same."

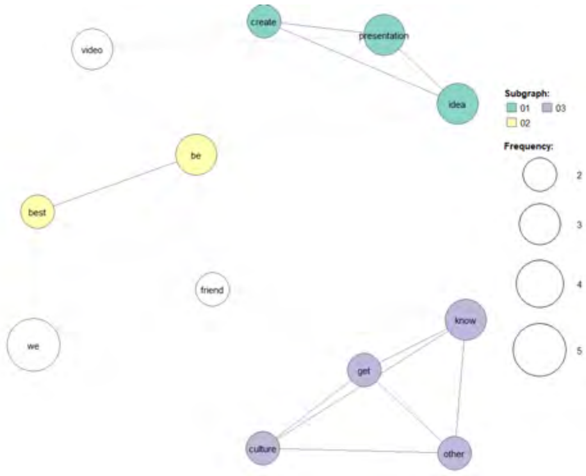


Fig.8 2020 Best experience

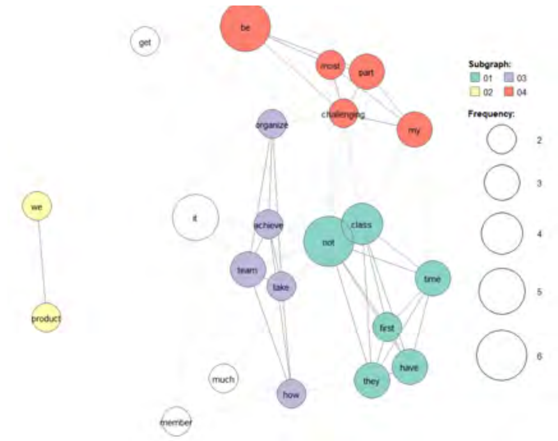


Fig.9 2020 Most challenging experience

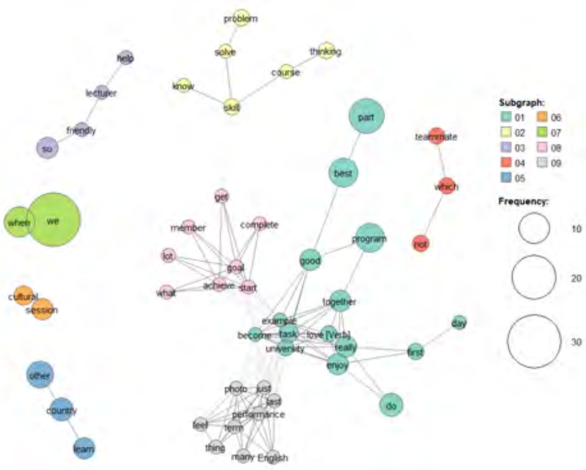


Fig.10 2021 Best experience

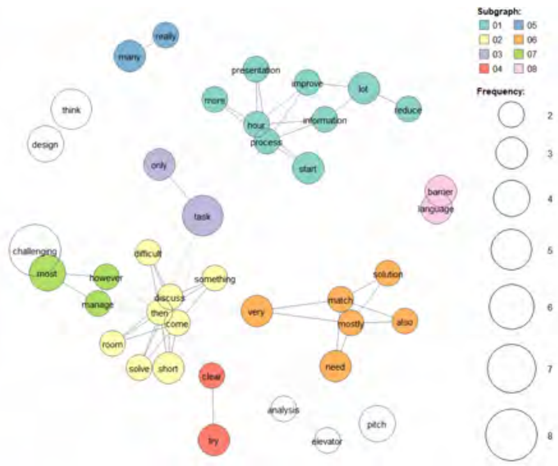


Fig.112021 Most challenging experience

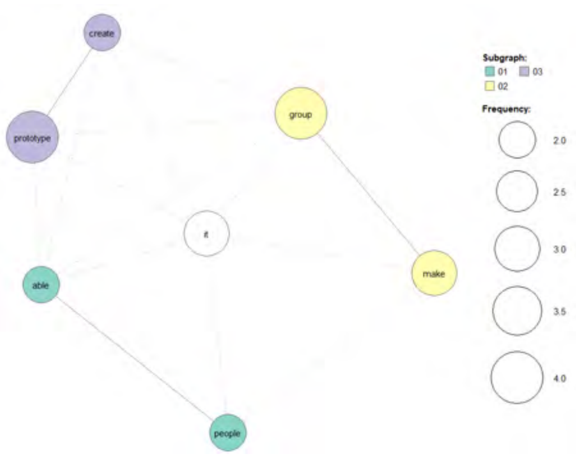


Fig.12 2022 Best experience

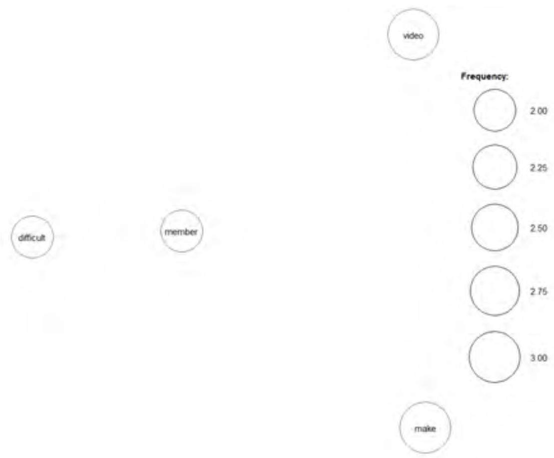


Fig.13 2022 Most challenging experience

Considering reflective statements about the quality of the learning experience brought about by GCL-DT-PBL is an excellent way to learn about the engagement of the participants. Fig.8-Fig.13 shows the co-occurrence network of participants' descriptions of their best and most challenging experiences during the 3-year program.

Commonalities were found in each year in what was interpreted through the described as the best. The participants were involved in teamwork and collaboration towards a common goal. To wrap up all the comments related to the bubbles that appeared in the analysis results above:

- 2020：The teamwork in idea creation led to the final presentation.
- 2021：Participants communicated and accomplished tasks together. They got to know each other better and better in working on the job.
- 2022：The group work allowed the participants to make prototypes and final presentations, make friends, and create something as a group.

The most challenging aspects and familiar to all years were: communication in English, teamwork, and time constraints. There were no descriptions of the degree of difficulty of the program itself. Here are some excerpts of KWIC concordance:

- I experienced how difficult communicating with other language people in English . Maybe , i did not speak correct English , but I was so enjoyed !!!
- This is the most challenging part because I am not better English speaker
- Video making as it was hard to communicate with group members thru online to get ideas
- To find the suitable time for all my groupmates for an external discussion and meeting to complete the work .

These results indicate that multicultural collaboration using English as the common language of communication is fun. Still, it also needs help communicating within the group for students uncomfortable with English. Some students also described time constraints, such as insufficient time to complete the task.

4 LIMITATION

As seen in the figure from the 2022 analysis, the sample size is affected by the response rate to the questionnaire. We need to improve the survey collection rate to grasp the overall response from the participants and prepare for the next program. Another limitation was the iterance of the cycle of the five stages of the Design Thinking process. The key to designing and manufacturing products and improving the products or systems requires constant *Kaizen*. Though the PBL deals with real-world problem-solving as a learning framework, we could not give the students enough time and opportunities to repeat the processes.

5 SUMMARY AND ACKNOWLEDGMENTS

5.1 Summary and Future Direction

This paper described the background of a multicultural collaborative PBL in the framework of Design Thinking conducted with the collaboration of four Asian universities. It showed the analysis result as part of an interim report of our 4-year project. The analysis mainly focused on student engagement, and content analysis methods using KH coder as a text mining tool were applied.

Findings are: The characteristics observed in GCL-DT-PBL participants over the past three years were consistent with the goals of this program. On the other hand, we also found that English may be a factor that can impede achievement.

The results of this survey support that this program was in line with the authors' common objectives. In addition, this analysis method allowed us to explore what words participants chose to describe in their responses and what could be read from the context. This helps to explore participants' thoughts that might not be picked up in a survey using the 5-point scale method.

On the other hand, the data size is relatively small because the program’s size is not that large. In addition, the nature of the post-program questionnaire collection, which depends on the students’ free will, has led to only a tiny amount of data being collected, as in the 2022 result. For example, formative evaluations could be added at several activity stages during the program to avoid this problem.

Step 1 and Step 2 of the Design Thinking Process showed a difference in perception of the problem. When cultural backgrounds differed within a team, points that seemed problematic to someone else sometimes did not mean as much to others. While the idea generation stage of Step 3 saw the most active participation, differences in viewpoints were observed again. Furthermore, during the team discussion to bridge the gap in views, there was a problem communicating this well using English, the common language. Step 4 prototyping and Step 5 testing had to be minimal effort due to the online nature of the project.

This paper can contribute to sharing two suggestions for future multicultural PBL design.

(1) Incorporate an approach from the perspective of cross-cultural understanding into program design to address real-world problem-solving.

(2) The need to make participants aware of the importance of additional linguistic efforts to bridge gaps in understanding due to differences in cultural backgrounds since English, the common language, is not the native language of all participants.

Future studies seek more in-depth research on how the participants improved their communication skills in English and, by that, improved their engagement.

5.2 Acknowledgment

This program has been partly supported by Ritsumeikan University Education Improvement Grant 2020-2023, and the author deeply appreciates their untiring support. The authors must remember the cooperation of all the students from the four universities who participated in the research. Last but not least, we authors sincerely appreciate the distinguished reviewers for taking much time and giving us constructive suggestions that helped us immensely. We hope this report paper could contribute to the SEFI community by sharing our outcome.

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ENGINEERING CURRICULUM REDESIGN: IS MY SCHOOL READY FOR THIS?

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Keywords*: Curriculum change, curriculum redesign, organizational readiness, institutional readiness, self-assessment tool*

ABSTRACT

As humanity keeps facing grand challenges engineers are expected to be at the forefront and keep providing sustainable solutions to extremely complex problems. In the meantime, we have reached an era where technological advancement moves at a very rapid speed. That poses a big question to academia. “How should we educate engineers to ensure that they are best prepared for a complex world?”

For an engineering curriculum to remain effective and relevant frequent redesign is critical. Despite this generally agreed upon understanding, universities sometimes operate under great pressure and move into initiating curricular change without having considered how multifactorial this process can be. At the same time there are

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little to no tools to help them determine institutional readiness for engineering curriculum redesign.

The Massachusetts Institute of Technology (MIT) has placed quality engineering education at the core of its mission since its founding in 1861. Since then, MIT has not only founded a great number of very advanced forward-thinking engineering programs, but has also collaborated with a big number of international governments and schools in order to guide and support their engineering curriculum change. The Abdul Latif Jameel World Education Lab (J-WEL) is a global consortium within MIT working on this exact topic. J-WEL staff are currently working with experts on said matter to develop a tool that universities could use in order to self-assess their initial readiness as well as their progress as they move on with their curriculum redesign process. This practice paper presents the first iteration of said tool.

1 INTRODUCTION

"Climate changes, water and food scarcities, a rapidly expanding population with longer life expectancies, increasing migration and displacement, looming threats of terrorism and nuclear deployment; are all posing mounting challenges for contemporary and future engineers" [1] Within this context, as humanity keeps facing grand challenges, engineers are expected to be at the forefront and keep providing sustainable solutions to extremely complex problems.

Although we live in a world of rapid technological development that often provides great solutions, this may come with a cost. Development in the field of Artificial Intelligence (AI) for example is expected to provide multiple solutions to these challenges and affect an increasing range of professional sectors, however "potential impacts of AI indicate both positive and negative impacts on sustainable development" [2]. In 2020 Vinuesa et. al. performed a first systematic analysis on "how AI can either enable or inhibit the delivery of all 17 goals and 169 targets recognized in the 2030 Agenda for Sustainable Development", and concluded that "AI may act as an enabler on 134 targets (79%) across all SDGs, generally through a technological improvement … However, 59 targets (35%, also across all SDGs) may experience a negative impact from the development of AI" [2]. Truby also points out how big tech's unregulated roll-out of experimental AI poses risks to the achievement of the UN SDGs, "with particular vulnerability for developing countries." [3]. Furthermore, when examining the future of work, "nearly all experts agree that machine learning, AI, and workplace automation following developments in these fields will replace many jobs worldwide" [4], while the COVID-19 crisis has only accelerated this transition.

1.1 Skills for the future

There is no doubt that today's workforce will need to learn new skills and to learn how to continually adapt as new challenges emerge and new occupations become critical. Defining the most desirable skill set while also designing educational reform and supporting sustainability is a hot topic of discussion among many academic and professional communities. According to Sarma and Bagiati while "fundamental scientific and technical knowledge is always vital, the development of such competencies as leadership, technical communication, cross-cultural communication, project management, leadership, team work, and problem solving are becoming more sought-after skills in the job market [5].” In the meantime, “as the world moves toward a digital economy, work is becoming more digital, remote, collaborative, and international” [5] while international virtual teams form and disband faster than ever. Examining the same topic, research by the McKinsey Global Institute [6] has looked at the kind of jobs that will be lost, as well as those that will be created, and it has inferred the type of high-level skills that will become increasingly important. According to their analysis the need for manual and physical skills, as well as basic cognitive ones, will decline, but demand for technological, social and emotional, and higher cognitive skills will grow. One more analysis was conducted by J-WEL. Over a period of two years, researchers analyzed 41 skill-related published frameworks and interacted with over 40 faculty, staff, and thought leaders [7]. From their research derives the J-WEL Matrix below (Figure 1).

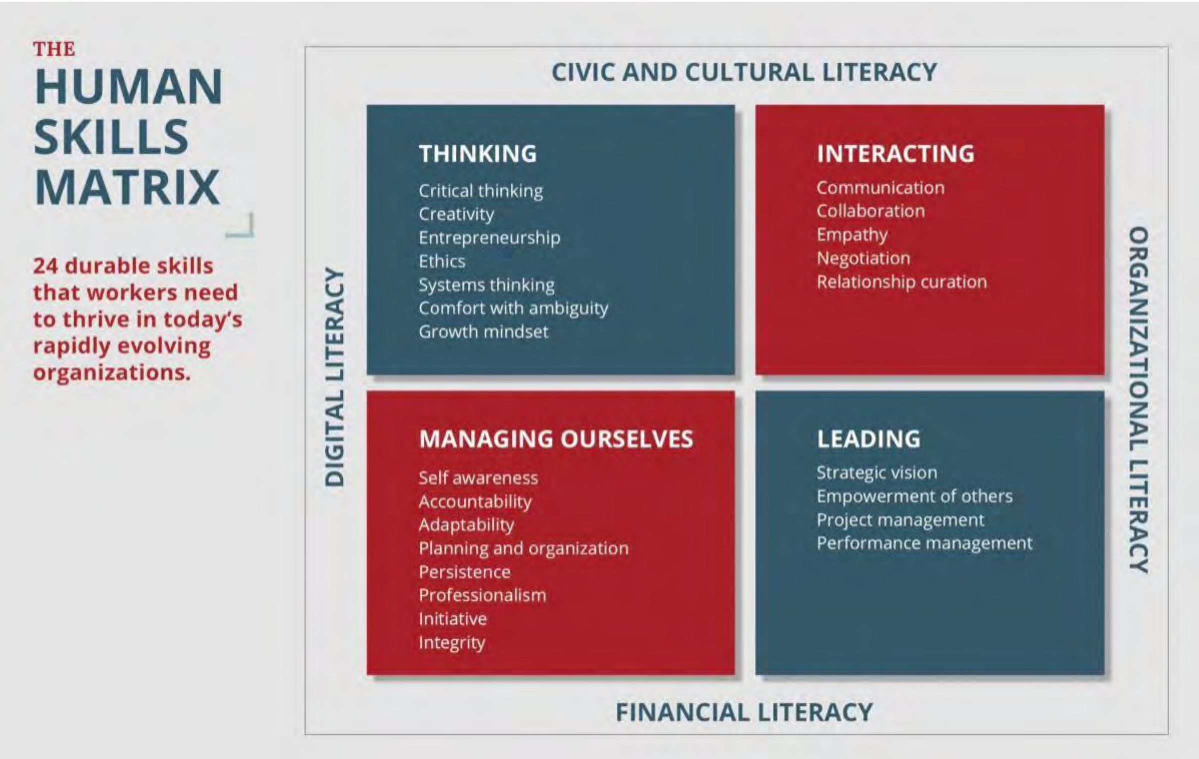

Fig. 1. The MIT J-WEL Human Skills Matrix (https://jwel.mit.edu/human-skills-matrix)

Within this context it is now critical for academic institutions to graduate students who can address the grand challenges of today and tomorrow with sustainability being at the epicenter of their academic philosophy. That will require updated curricula and employment of new pedagogical methods to best support this goal, and also the involvement of multiple stakeholders that will need to support this mission.

2 SUSTAINABILITY AND EDUCATIONAL TRANSFORMATION AT MIT AND BEYOND

MIT addresses issues and topics of sustainability and grand challenges through a variety of different platforms and approaches. One such approach is the MIT Office of Sustainability. By utilizing the campus as a testbed and incubator, this office aims “to transform MIT into a powerful model that generates new and proven ways of responding to the challenges of our changing planet.” [8] Relevant to engineering curriculum, the Office of Sustainability supports multiple sustainability minors (defined in the US as a secondary area of specialization beyond a college major degree program) that are multi-disciplinary and works to ensure that sustainability is fully integrated into teaching. Another initiative towards the same direction is the establishment of the New Engineering Education Transformation program, where students from various majors collaborate in highly multidisciplinary teams to work on authentic problems. The ideas of sustainable development are clearly rooted within the Climate and Sustainability program thread.
Educational innovation has always being at the heart of MIT, in order to promote excellence and transformation in education at MIT and worldwide. In 2017 the Abdul Latif Jameel World Education Lab (J-WEL) was launched as a joint initiative between MIT and Community Jameel. This consortium engages with global partners through a membership program. The majority of members are universities from across the globe that are addressing a specific challenge or goal they have within their own campus. In specific cases, the work of members may warrant a larger custom project that will engage J-WEL staff, MIT faculty and the members. Goal of the members is very often course and curriculum design as well as change of management and systems thinking within their higher education institutions.

2.1 Readiness Assessment Tool

While working with multiple members for years it has become obvious to the J-WEL team that member institutions often lack the understanding of how complex and multifactorial the process of redesigning an engineering curriculum can be, in order to successfully address all aforementioned needs. At the same time, when conducting a literature review there was little to no information at all regarding preparing and guiding an engineering school through the curriculum redesign process and the necessary organizational change process, especially one that would reflect state of the art educational needs. With this gap in mind authors engaged into the design and testing of a tool that could introduce member universities to all factors deemed essential during their curriculum redesign journey, that could also be used by them as a self-assessment mechanism helping them to track progress.

3 METHODOLOGY

3.1 Designing and Testing the Readiness Assessment Tool

Authors of this paper based the first development on two documents. First is the Sarma and Bagiati paper [5], commissioned by the National Academies of Engineering, discussing equity needs for the future and presenting 10 current pathways to innovation in STEM education (Table 1.) The second paper is a very detailed presentation of the development of a tool measuring organizational readiness for curriculum change in the medical field [9]. Authors adapted the aforementioned tool, specifically in terms of the critical factors, in order to reflect current needs in engineering education, and then asked five experts to go through each item presented in the tool and rate it according to their perception of importance during the process of engineering curriculum redesign (with 1 being the least important factor and five being the most important factor), as well as providing additional recommendations about factors they consider critical. The panel of five experts consisted of two MIT faculty and one program director all with extensive experience in developing engineering schools and programs, and two faculty from institutions that have collaborated with MIT in the past when designing/reviewing their engineering curriculum.

Table 1. Innovations in STEM Education [5]

1. Applying Active Learning Pedagogies	2. Implementing Competency Based education
3. Adopting a Multidisciplinary / Integrative Approach	4. Supporting beyond classroom learning experiences
5. Providing flexible, cost-efficient educational paths to continuous learning	6. Enhancing Inclusive Entrepreneurship and Innovation
7. Providing advanced support mechanisms for educational research and development	8. Developing new credentials.
9. Support connections with K-12 and peer learning/mentoring	10. Enhancing sharing and dissemination of information

4 RESULTS

Table 2 presents the organizational readiness assessment tool as well as the mean score as provided by the five experts for each category of the tool. The first two questions do not have a score, but developers think that these are questions important to clarify and consider at the beginning of the process, as they also guide the curriculum redesign process. It is expected that different countries follow different top-down or bottom-up approaches when it comes to topics such as introduction of educational innovation. Furthermore, depending on the country, there may be different governmental influences in academia.

The scale used was 1-5, with one being the least important factor and five being the most important factor (factors scored below were considered more important the closer they are to 5). Those ranked as being the most important factors by our expert respondents include ‘Focus on training students on professional/soft skills’; ‘University leadership is supportive of the curricular change’; and ‘Faculty and teaching personnel duties are clearly aligned to the goals of this change’.

Table 2. Organizational Readiness Assessment Tool for Engineering Curriculum Redesign.

Theme	Factors	Expert Score
Pressure to Change initiated from the	1. University Leadership 2. Faculty 3. Government 4. Students 5. Industry 6. Community 7. Alumni	
Necessity to Change	1. Future of work 2. Grand challenges that need to solved	
Appropriateness	1. The new curriculum will focus on training students on professional/soft skills 2. The new curriculum includes real life problems as identified by the community/industry 3. The new curriculum is guided by the latest findings of the science of learning 4. The new curriculum will focus on training students for state-of-the-art technical skills 5. The new curriculum aligns with requirements as stated by local accreditation mechanisms	4.60 4.40 3.83 3.80 3.75
Management & Leadership support	1. University leadership is supportive of the curricular change 2. University leadership is willing to provide time to staff and faculty involved in the curriculum change process 3. Government is supportive of the curricular change 4. University leadership has effective systems in place to support the change 5. University leadership is willing to provide resources 6. Government has effective systems in place to support the change.	4.80 4.20 4.00 3.80 3.40 3.40
Staff culture: Faculty and teaching personnel …	1. ...are willing to innovate and/or experiment to improve teaching 2. ...cooperate to maintain and improve effectiveness of teaching 3. ...feel a sense of personal responsibility to improve teaching and learning 4. ...are ready for co-teaching a multidisciplinary / cross-disciplinary course	4.40 4.40 4.40 4.25

	5. ...discuss this change with each other in both formal and informal situations 6. ...work together as a team 7. ...are receptive to changes in the curriculum 8. ...share responsibility for the success of the curriculum redesign 9. ...university leadership has effective systems in place to support the change 10. ..are ready for co-teaching a traditional course	4.20 4.20 4.20 3.80 3.80 3.50
Formal Leader of this Innovation…	1. ...accepts responsibility for the success of this project 2. ...cooperates well with the both university leadership, faculty and teaching personnel 3. ...has the authority to carry out the implementation of this change 4. ...has been identified	4.40 4.20 4.20 4.20
Key stakeholders involved	1. Have all stakeholders been identified? 2. Have all stakeholders been involved?	4.20 4.00
Project Resources	1. Faculty and teaching personnel training on new content 2. Faculty and teaching personnel awareness of this change 3. Evaluation mechanism 4. Faculty and teaching personnel training on new pedagogies 5. Expert staffing 6. Facilities 7. Equipment and materials 8. Financial resources	4.40 4.40 4.20 4.20 4.00 3.80 3.40 3.40
Clarity of Missions and Goals	1. Faculty and teaching personnel duties are clearly aligned to the goals of this change 2. Curriculum developers presented clear goals and objectives regarding the new curriculum 3. Faculty and teaching personnel understand how the change fits in with the desired competencies of learners	4.60 4.40 4.20
Implementation Plan	1. ...acknowledges faculty and teaching personnel input and opinions 2. ...includes appropriate training 3. ...includes a plan for improvement based on recurring evaluations 4. ...identifies specific roles and responsibilities 5. ...describes tasks and timelines	4.20 4.20 4.00 4.00 3.80

FUTURE WORK

Authors are currently incorporating additional expert suggestions, and will first share the tool with J-WEL's university-members who are currently working on curriculum development and reform, receive further feedback from members, and use this opportunity reiterate and improve the tool. Particular attention will be paid in order to identify cases in which what the tool suggests may be counter to local legislations, conditions, academic cultures, and protocols. Members are expected to use this tool when they will start planning their curriculum design/redesign, but also use it for regular check-ins throughout the process to identify and measure progress.

Following this stage, authors will make the updated version of the tool open and useable for all and share widely via the J-WEL website.

Furthermore, there is opportunity for future work by sharing this tool with policy makers and determining if it may influence the way they design educational policy and how they might support and encourage academia partnerships with local communities and the industry.

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MAKING MEANING TOGETHER: AN AUTOETHNOGRAPHY STUDY ON OUR ROLE IN ETHICS EDUCATION

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***Keywords**: autoethnography, narrative, community of practice, ethics education, Eastern Europe*

ABSTRACT

Representation of diverse people's perspectives, cultures, and ideas enriches societies. Equally important for communities to flourish is to have diverse perspectives on what good ethics education is. For 50 years the European Society of Engineering Education (SEFI) has been uniting and supporting engineering educators and researchers from around the globe and particularly from Europe. However, involvement from institutions in Eastern Europe is still very low. To diversify and strengthen the community by bringing perspectives from these countries, we engaged in an autoethnography study to share insights on participation barriers broadly and ethics education, more specifically. We choose autoethnography as this methodology allows researchers not only to share their own experiences but to connect in making meaning of a phenomena and to form a community of practice. The researchers and authors of this paper are representing STEM institutions in three Eastern European countries. Applying an interactionist approach, we engaged in a community of practice group to discuss the current state of the art of ethics education in our own institutions and to talk about the experiences with ethics education, academic integrity, and ethics culture. We collectively selected an appropriate framework and applied that framework to interpret the findings. Transcripts were analysed by all five researchers. The paper and the presentation will be presented together as a narrative story. The goal of this work is to form a community of practice and to create an agenda to engage the newly formed community of practice with the broader SEFI ethics education community.

1 INTRODUCTION

1.1 Motivation

The EU STEM Coalition is an EU-wide network supported by the Erasmus Programme that works to build better STEM (Science, Technology, Engineering, Mathematics) education in Europe. The European Commission (2020) claims that in most EU countries there is a shortage of educators across all fields of study, and particularly in STEM disciplines. Moreover, the report claims that educators need continuous opportunities for professional development, teaching in multilingual and multicultural classrooms, and opportunities for cooperation between higher education institutions [1]. The report further suggests that international mobility of students and educators must become part of educators training to broaden the access to the diversity of quality teaching approaches [1].

The communication report sets an agenda to be reach by 2025 with major focus on objectives such as: 1) *connectivity* among higher education institutions and with their surrounding ecosystems and society; 2) *inclusion* to ensure accessible higher education institutions, open to a diverse student and researcher body; 3) *integration* of learning and training for sustainable development across all disciplines through an interdisciplinary and challenge-based approach, where innovation is an important component.

At the heart of all the above objectives, representation of diverse people's perspectives and ethics education considering all stakeholders and State Members, are regarded as the essence to build better STEM education in Europe.

Educational innovations, connectivity, inclusion, and integration, including best practices in teaching, as researchers suggest, happens more quickly through direct connections between people rather than dissemination through the literature [2]. In coordinating STEM ethics education community level support efforts to include diverse representation of scholars across Europe, is to develop a Community of Practice (CoP) to foster connections between educators and researchers. Utilising an autoethnography study, this narrative paper aims to synthesise the experiences in teaching ethics of five scholars who are interested in forming a CoP. A CoP can have a variety of structures and it can be formed and run explicitly by members or can have external facilitators. The meetings can vary from explicitly virtual, hybrid or in-person, only a few times a year to multiple times per month, and they can be implemented on any scale, from international to unit-level [3].

While in some CoPs, incentivization for CoP members is formally recognized by an organisation, in our CoP as in many other CoPs, members have an intrinsic motivation to engage in CoP as the opportunity to network, learn from each other, and to engage in professional development [4-7]. Particularly, members in our CoP benefit from the common values of CoP structure, such as having a space for us to come together and collaboratively work on challenges, while also providing safe spaces for members to reflect on their own practices. CoPs allow members to easily access the collective knowledge and expertise of the group and to rely on others for professional or emotional support [7]. Further, to sustain our newly formed CoP, we plan to meaningfully coordinate resources and the accumulation of collections of knowledge and best practices. These benefits position our CoP as a powerful mechanism for supporting and sharing educational innovations, connectivity, inclusion, and integration as set by the European Commission agenda for Achieving the European Education Area.

1.2 Theoretical Framework

The foundation of the CoP framework is based on the Situative perspective on learning where social interaction is essential for our learning and knowledge-gaining [3]. According to Wenger and colleagues, CoPs have three elements: *domain* of interest (knowledge and problem focus) they are centred on, *community* of people that comprise the group, and *practice* that members share and innovate around [3, 4]. Applying an interactionist approach, the authors of this work reflect on the current state of the art of ethics education in our own institutions and chose to engage in a CoP to improve our practice with the support of others by providing a structured group environment that allows for strong connections to form [4].

2 METHODOLOGY

2.1 Autoethnography

Autoethnography is a qualitative method approach that helps researchers to describe and systematically analyse personal experience to understand cultural experience [8]. The researcher blends autobiography and ethnography, engaging in a method that is both the process and the product. To construct the narrative, the facilitator of our CoP developed open-ended reflective prompts with the intention of providing enough scope and context to yield responses that capture different perspectives on similar experiences. As Wenger [4] emphasises the domain of interest, the community, and the practice are the essential elements of a CoP, our prompts progressed through the stages of exploration of the domain of interest of ethics education (why and how to teach ethics); our own lived experience (our role in teaching ethics), and lastly, meaning making through the CoP to develop and maintain the CoP core knowledge.

2.2 Data Analysis

The interactions approach builds upon the co-creation of the narrative. The narrative-inquiry autoethnography approach allowed the researchers, as a group, to examine significant experiences from our own perspectives having lived through them. The narrative inquiry and reflective writing allowed us to write about our own experiences to generate a data set for analysis and meaning making to present our collective views as a community of practice. Qualitative thematic analysis was used to iteratively generate common codes, to then be grouped around common themes as the main areas of interest for this work.

Our autoethnography method involves the following process: firstly, the facilitator posted four prompts on shared space where all authors have secured access to the file. Authors, then independently in the form of narratives addressed the prompts. All authors were able to see each other's responses as the narratives were evolving. Secondly, the facilitator coded through an inductive thematic analysis all narratives for initial emerging themes. Thirdly, the narratives were coded by each author individually. The authors then built consensus and merged their individual code lists and created a unified codebook before conducting a second iteration of individual coding. Key themes (meaning making) were identified from groupings of the final code list to inform the analysis. The final analysis and key themes are presented in this paper.

2.3 Rigour and Trustworthiness

Autoethnography often is criticised by the research community as being self-indulgent and not sufficiently rigorous, however, scholars from multiple disciplines argue that there should be and there is a place for research that links the personal with the cultural. Some researchers suggest that autoethnography can encourage empathy and connection beyond the self of the author and contribute to sociological understandings [9]. In this co-created narrative, we autoethnographically linked personal experiences of implementing ethics education in the STEM curricula and being included in the larger SEFI community with pertinent issues reflective of research culture to contribute to understandings of challenges of participation and inclusion in the SEFI community. It is up to this larger community and gatekeepers of research to allow the sharing of perspectives and with a variety of research methodologies and styles of representation. The findings of our autoethnography study could be compared with findings from the broader literature on STEM ethics education and Community of Practice. That comparison could be an evaluation criterion of rigour and trustworthiness, of course considering the phenomenon of the lived experiences and cultural backgrounds.

3 RESULTS

The initial key ideas and impressions emerging from the reflections were grouped and organised into thematic sections by the facilitator of the CoP, resulting in twelve emerging themes. Then the narratives were coded by each author individually and consensus to merge their individual code lists was reached. Sixteen key themes (meaning making) were identified from groupings of the final code list to inform the analysis. The final analysis and key themes are presented in Table 1 below, organised in an order of the four prompts: 1) why should we teach ethics; 2) how should ethics be taught; 3) what is an educator's role in teaching ethics; and 4) how do we deepen our understanding of ethics education through community.

Table 1. Key themes from the four prompts and meaning related to CoP

Prompt	Themes	Meaning related to CoP
Why should we teach ethics?	Prepare students for post-graduation **success**. Allow students to develop **critical thinking skills**. Help students become **better decision-makers**. Support students' **development of academic, social, and emotional competencies**. Introducing students to **emerging areas in STEM** - AI and robotics that raise **new ethical questions** are rather different from other engineering disciplines. To make students understand the impact (**risks, outcomes etc) of professional activity** in a broader, societal context.	Domain and interest of the CoP members

How should ethics be taught?	**Theoretical foundations** in **moral** and **ethics** education. **Case studies** - a balance between explaining why and demonstrating how. To elicit **moral emotions** and hence intuitions to see how reliable these are for **our shared living** within the academic community.	Expertise and practice Learning from each other Identification of best practice examples
What is my role in influencing the adoption of ethics in the curriculum?	**Role-modelling**. **Historical** and **cultural** influences. Identification of emerging issues connected with **new technology applications**.	Challenges Resources
How do we deepen our understanding of ethics education through community?	**Value-added** – intrinsic motivation to participate in the CoP. **Belonging** to a community with similar backgrounds (geographical, historical, and social). **Resource sharing**. **Common activities**, seminars, and exchanging experiences.	The benefits of Community of Practice

The largest number of themes (6 themes) emerged from the responses to the first prompt - *Why should we teach ethics*? These themes were linked to the specific STEM domain as well as the professional interest of the CoP members. A couple of quotes, provide a description of the themes in this prompt - "*Teaching Ethics is not about teaching Ethics. It is about teaching how to see your professional activity in a broader context. Engineers, executing their professional tasks, serve society."* and "*There are many reasons for teaching ethics, ranging from those related to the moral and social development of each student to those related to the wise governance of technology and its implications*."

There were three key themes emerging from responses to the second and third prompts, respectfully - *How should ethics be taught?* and "*What is my role in influencing the adoption of ethics in the curriculum?*". The following quotes represent descriptions of the themes in these two prompts: "*What works best is a brief theoretical introduction followed by real life examples related to the theoretical part. Then we apply a problem-based approach when we present a list of problems (in advance)…Of course, with new technologies there will be new questions that will probably need* *different approaches*." and "*taking a pensive stance, arguing how to assess its design, affordances and functionalities from a moral and epistemic perspective…the first goal is to elicit moral emotions and hence intuitions in order to see how reliable they are for our shared living within the academic community. Then we proceed to see the intricate relationship between those intuitions, i.e., beliefs, and the moral values, principles and norms that ground our communal existence."* These themes in the second prompt are linked to the expertise and practice of the CoP members, as well as an opportunity to learn from each other and identify best practice pedagogical examples.

The themes in the third prompt were linked to the opportunities of the CoP members to share challenges and resources, including helping students to feel belonging to the larger community of STEM ethical practitioners - *"My role, and that of my colleagues, would be to maintain a strong interest in the field, an interest that stems primarily from the practical nature of ethics in assessing everyday situations and making informed decisions, thus creating a positive social output. I recognise that the professional role of ethics is rather secondary for undergraduate students and is given more attention as an exercise in discovering and growing moral virtues to better situate themselves in the world of technology, not just as users but as creative agents. For students, I prefer a mix of personal exploration and ethics as a tool for professional endeavour."*

The last prompt in this authoethnography study was "*How do we deepen our understanding of ethics education through community?*". Addressing this question, the authors of this paper individually identified the benefits of forming and participating in CoP and then collectively agreed on these benefits (meaning making). The following quotes best describe the key themes in this category: *"This sense of belonging can be reinforced with reference to ethical questions within other courses and disciplines. Evidently, increasing interest in research on ethics can also contribute to an increase in the interest and awareness on the subject in our institutions." and "We can also try to identify a call for projects (e.g., in Horizon Europe) that corresponds to these ideas. In addition to the professional part, we should introduce the topic to the broader public.*"

4 SUMMARY

As the initial work for establishing a Community of Practice is completed through the process of writing this conference paper, we plan to sustain the group by creating more networking opportunities starting with monthly meetings in the coming academic year. We plan to expand the group and create a space where we can share teaching resources (videos, assessment rubrics). We further plan to engage with the CoP with invited talks, seminars in each other's universities and at conferences, with the goal of establishing collaborations to complete studies together, publish, and eventually apply for funding to work on joint projects.

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CERTIFICATE-BASED GOOD PRACTICE TO MOTIVATE ENGINEERING STUDENTS TO LEARN SUSTAINABILITY SKILLS

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ABSTRACT

Engineering plays a crucial role both in addressing sustainability challenges and in helping to achieve the sustainability transition. However, tackling the complex problems of sustainability needs a broader understanding of these issues from non-engineering perspectives as well. The Department of Environmental Economics and

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Sustainable Development of the Budapest University of Technology and Economics (BME), Faculty of Economics and Social Sciences (GTK), has developed a unique method for a uniform certification of studies in the fields of sustainability, environmental economics, and environmental management for engineering students. The so-called green certificate is provided after the successful completion of at least five elective courses such as sustainable business models, green economic development, smart and sustainable digitalisation-related solutions, sustainable rural or urban development, sustainable energy management or climate change oriented courses etc. The certificate can be obtained either in the framework of a bachelor's or master's degree programme, and it is available both in Hungarian and in English, even for incoming mobility students. By achieving the green certificate, the engineering students gain a complex vision, a sustainability mindset and a truly green attitude. Our study analyses the green certificates' data quantitatively, focusing on the engineering students' profiles and the most frequently chosen courses. Our results can help further refine our methods to reach even more engineering students, and it can serve as a good practice to follow for other universities.

1 INTRODUCTION

1.1 General Introduction

Engineering plays a crucial role both in addressing sustainability challenges and in helping to achieve the sustainability transition. However, tackling the complex problems of our time requires expertise from multiple disciplines, as social, environmental and economic challenges are often not only impossible to understand but also impossible to solve using a single perspective or knowledge framework due to their complexity (James Jacob 2015). Engineering practice has also become more and more multidisciplinary in the last decades (Lattuca et al. 2017). Engineering education, therefore, needs to be complemented with knowledge from non-engineering disciplines to address complex problems, and a holistic pedagogical approach has to be applied (Kövesi et al. 2021). The main aim is to train students who are sustainability literate (Sterling and Thomas 2006) and have the competences needed to solve sustainability challenges (Bianchi 2020). As university curricula are structured by disciplines, the application of inter-, trans- and multidisciplinary approaches is not a clear and easy process, especially in engineering education. Even though these methods share the same fundamental ideas, there are major differences between them. Interdisciplinary education requires multiple disciplines to create a synthesis of their knowledge and methods, transdisciplinarity constructs an intellectual framework that is unified beyond disciplinary perspectives, while multidisciplinarity is a more individual approach where the joint efforts involve the juxtaposition of different disciplinary viewpoints (Stock et al 2011; Marques 2008). These methods encourage the capacity to comprehend complicated issues and take appropriate action, which is consistent with the aims of education for sustainable development (Annan-Diab and Molinari 2017). Sustainable practices are often integrated into engineering programs by either creating or offering stand-alone courses added to the curricula or by integrating them into one of the already existing courses (Mesa et al.2017). These approaches are essential in reshaping engineering education to complement the engineering skillset with competences form other disciplines, such as management and social sciences thus preparing the engineering students to understand and solve complex problems from different perspectives.

1.2 Green Certificate

The Green Certificate is a great example of providing complex sustainability knowledge in a multidisciplinary learning experience for students of engineering and natural sciences. It is an initiation of the Department of Environmental Economics and Sustainability at the Budapest University of Technology and Economics Faculty of Economic and Social Sciences (BME-GTK).

The Green Certificate is not an accredited diploma, it is a supplementary verification of completed sustainability management courses. It has more than 30 years of history starting in the early 90s. Former students asked the department about the possibility of some kind of recognition of their sustainability-related studies to be used in the labour market. The department developed the green certificate as a response to this request. To obtain a green certificate the students have to complete at least five of the courses advertised and taught by the Department of Environmental Economics and Sustainability during their studies as elective courses. This can be done either during the bachelor's or master's degree course or during the two courses together. The courses are available in both English and Hungarian, therefore international students can also participate. The completion of English courses can be a good preparation for Hungarian students as well to support the preparation for studying abroad or for multilingual jobs (multinational companies, EU institutions). There is a broad portfolio of subjects available including the fields of corporate environmental management, climate change, sustainable regional development, sustainable business models and EU environmental policies, etc.

Students from all educational programmes at BME can apply for the certificate, the only exceptions are students from the Master’s in Regional and Environmental Economic Studies and the Master’s in Environmental Engineering specialization of Environmental Management, as their compulsory core subjects include already the required courses. After the completion of the five elective courses, the students have to request the green certificate by filling in a simple online form on the Department’s website. Each semester the department organizes a graduation ceremony where the green certificates are handed out. The actual green certificate provides information in both English and Hungarian on the number of hours and courses in environmental economics and management that the holder has completed. The green certificate is a tool for conscious career development, since based on the informal feedback of former students, the certificate can be an advantage in job applications.

2 METHODOLOGY

The main objectives of this practice paper are to provide a quantitative analysis of the Green Certificate based on the related administrative data from the last five years - between 2018-2023. The aim of our paper was two-folded, firstly to showcase this successful local best practice on how to integrate a multidisciplinary educational approach into the engineering programmes, and secondly, to formulate recommendations for future developments based on the data analysis. The methods used for the quantitative analysis are descriptive statistics and exploratory data analysis. We built our conceptual framework based on existing literature summarized in the introduction part about the importance of multidisciplinarity in education. The actual data for the analysis were retrieved from Neptun, the online educational administration system that holds all academic data and personal information of the students. We focused on the frequencies and percentages related to the participating students, and their chosen courses, and we used graphical display methods to present the results. Based on the lessons learnt we formulated recommendations for further improving the impact of the program.

3 RESULTS

As it was previously mentioned, the retrieved data covered 5 years starting from June 2018 till March 2023. During these years and months, all together 909 students completed successfully the requirements and applied for the green certificate. Fig. 1. shows the number of certificates per academic year, and it only counts with 859 certificates, as 50 certificates were obtained before September in the academic year of 2018/19. The data for the 2022/23 academic year is not yet complete. The key finding is that COVID-19 did not have a negative effect on the number of green certificates issued, the opposite is true: most certificates were issued during the two worst years of the pandemic (2019/20, and 2020/21). There is a significant fallback in the number of certificates in 2021/22 by almost one-third. Further investigation is needed to discover the potential reasons behind the fallback and the final results of 2022/23 should also be added to see whether the decline is continuing.

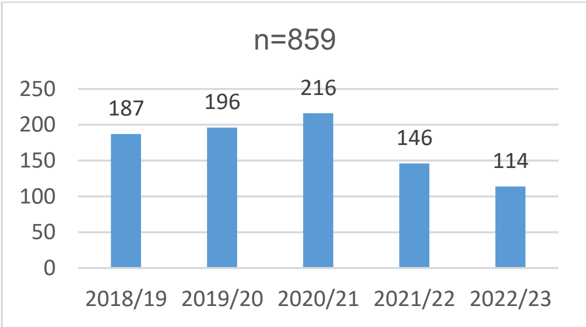

Fig. 1. Number of issued Green Certificates for 5 academic years

Fig. 2. shows the ratio of different fields of study among those 909 students who obtained their certificates between June 2018 and March 2023. More than 60% of the students study engineering, and 31% have a management background. There was only one PhD engineering student, and one from natural sciences giving less than 0,3 % of the total throughout the 5 years. The key results from these data are to increase the number of students participating in the Green Certificate program from the Faculty of Natural Sciences, and also potentially PhD students from any faculties.

We were also interested to see which level of study is represented the most among the participating students (Fig. 3.). The results mostly matched our expectations, as the majority of the students belonged to bachelor-level studies, however, it is surprising how much higher the ratio is – a little more than 92% (almost 62% engineering, and 31% management students), whereas only 7,5% students studied at master level among the participating students. There are much more bachelor students at BME than master students, however, there is a place for improvement in recruiting more master-level.

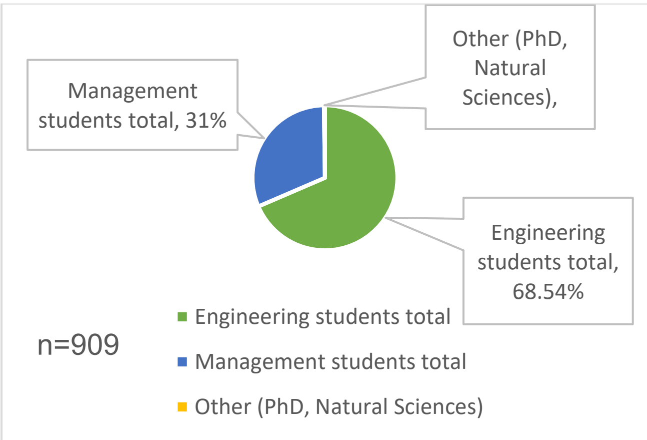

Fig. 2. Ratio per Fields of Study 2018-2023

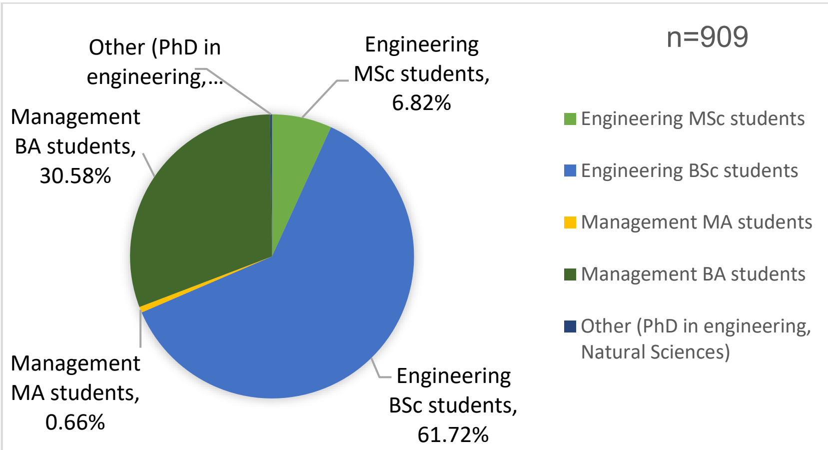

Fig. 3. Ratio of level of studies among those awarded with Green Certificates between June 2018 and March 2023

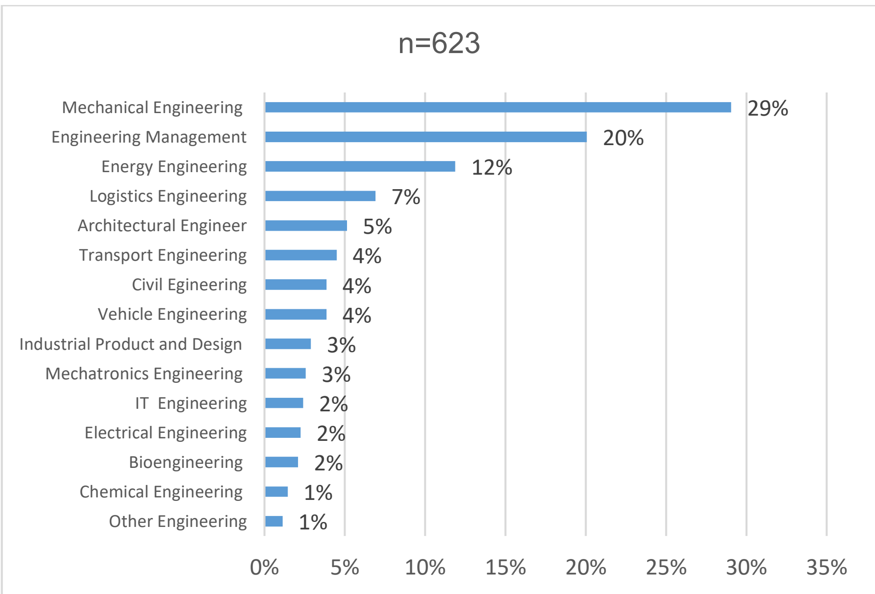

Fig. 4. Different fields of study of engineering students

All faculties from BME are represented among those who obtained the Green Certificates. Fig.4. shows the ratio of students from different engineering studies. The highest ratio of the students awarded studied Mechanical Engineering (29%) either at bachelor or master level, the second highest ratio is from Engineering Management (20%) from the Faculty of Economic and Social Sciences, the third highest is from the Energy Engineering students (12%). Some engineering fields are very underrepresented, such as Chemical and Bioengineering (1% and 2%) and Computer Science Operational Engineering (below 1%).

The international students and courses ratio in the Green Certificate program is very low. The non-Hungarian student ratio is less than 1% - there are only 8 students out of 909 who are non-Hungarians. Sometimes Hungarian students also choose courses held in English, therefore all together 71 English courses were attended out of the 4801 total course number.

Table 1. shows the top 10 list of courses chosen by the engineering and management students separately. The list is different for the two groups even in the top three places. The most popular course in both cases is Environmental Economics. The course Waste Management is also widely chosen by both groups, it is in second place for engineering, and third place for management students. The third place for engineering students is Environmental Management, while Strategic Planning of Climate Protection is the second place for management students. This latter course is completely missing from the list for engineering students together with the Sustainable Business Models course. Climate Change – Advanced level, and the Environmental Management Systems courses are missing from the management students' list but appear on the engineers' top ten list. The courses that appear in both lists but in different places are Environmental Law, Environmental Practices in Energy Management, Environmental and Regional Policy of the EU, Regional Economics, and Human Nature vs. the Natural Environment.

Table 1. The 10 most popular courses among engineering and management students

Engineering Students n= 3268		**Nr.**	**Management Students** n= 1512	
Environmental Economics	16%	1	19%	Environmental Economics
Waste Management	15%	2	13%	Strategic Planning of Climate Protection
Environmental Management	10%	3	12%	Waste Management
Environmental Law	8%	4	11%	Regional Economics
Climate Change – Advanced level	7%	5	11%	Sustainable Business Models
Environmental practices in energy management	7%	6	7%	Environmental Management
Environmental and Regional Policy of the EU	6%	7	5%	Environmental Law
Regional Economics	5%	8	5%	Environmental practices in energy management
Environmental Management Systems	4%	9	4%	Environmental and Regional Policy of the EU
Human nature vs. the natural environment?	4%	10	3%	Human nature vs. the natural environment?

4 SUMMARY AND ACKNOWLEDGMENTS

In this practice paper, we have overviewed the Green Certificate program. We examined with quantitative methods through descriptive statistics and exploratory data analysis the data from the last five years (2018-2023). We have seen that the Green Certificate is widely known among the students of the university, during the 5 years more than 900 certificates were issued providing sustainable management competences to engineering and management students. In conclusion, we can say that the program is indeed successful as a multidisciplinary approach for sustainability competences among engineering students. The weakest points are internationalization and involving master and PhD level students. There are a lot of similarities in what topics engineers and management students consider important, but there are significant differences as well that could be addressed when planning and designing the available courses. Overall, this model is suitable to be implemented in other universities as well.

The limitations of our research include its presentation solely based on the data available from our administrative system. It was beyond the scope of this paper to conduct a survey or interviews among the participants. Therefore, in the future, we plan to conduct both quantitative and qualitative research among green diploma holders to explore whether the students obtained a comprehensive sustainability mindset as a result of their studies and the impact of the green diploma on their employment.

We have formulated the below recommendations based on our results to further improve the Green Certificate program.

- A communication campaign could be organized at the university in English targeting Erasmus incoming students and regular foreign students to increase the international student participation ratio in the Green Certificate program.
- A communication campaign should also be organized for Hungarian students from the fields that are less represented in the program: natural sciences, all master and PhD level students.
- To further develop the level of sustainability integration in the engineering programme curricula, designing new interdisciplinary courses together with the engineering departments might be beneficial.
- To develop an e-badge as a digital proof of the recognized green competences that allow the students to showcase them on digital platforms. This can be a more suitable solution for the younger generations, and it can increase the popularity of the program.

This study was supported by the UNKP-22-3-II, the UNKP-22-5 New National Excellence Program of the Ministry for Innovation and Technology and the Bolyai János Research Scholarship of the Hungarian Academy of Sciences. This endeavor would not have been possible without the help of colleagues Katalin Käsz and László Valkó, PhD, who provided valuable input, insights, and assistance for this paper.

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WHY AND HOW DO STUDENTS NEED TO HAVE THEIR MENTAL HEALTH CONSIDERED IN ENGINEERING SCHOOLS?

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Keywords: *Mental Health, Prevention, Analysis*

ABSTRACT

This paper addresses the students' mental health in higher education and more specifically in engineering schools. Several studies have shown student mental health

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and wellbeing can affect students’ academic performance. We investigate how student’s mental health is considered in engineering schools as well as how it should be and study the case of our engineering school.

First, we present several research and studies conducted on how mental health is considered in higher education and its impact on academic performance.

In the second part, we study the case of our engineering school with the implementation of a survey among students and teachers to collect their feedback. We add to this survey a collection of testimonies from students. We will analyse how mental health is considered and the impact of addressing mental health on student success in an engineering school.

Finally, we present possible solutions to improve the consideration of mental health. These solutions are aimed at administrations, teaching staff and engineering school students. Indeed, the consideration of mental health must be global and concern the entire educational organisation.

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1 INTRODUCTION

1.1 Background

Student mental health remains a subject that is not sufficiently addressed (Morvan and Frajerman 2021) in France. Currently in France, higher education institutions are not required to have indicators on the mental health of their students. Yet student ill-being is a major issue. Several studies on the emotional distress of European and North American students highlight this ubiquitous problem, less frequent in non-student populations of the same age. In 2013, 20% of 10–24-year-olds were subject to mental health problems each year (depression, anxiety). More recently, after the COVID crisis, a survey carried out by a health insurance company (LMDE) indicates that in 2022, 68% of students in France were in a situation of ill-being. 52% said that Covid had affected their social interactions with friends and family, 44% their emotional and family life. In addition, more than half of the students interviewed were afraid that their degree obtained during the health crisis is devalued.

Student ill-being is defined in our article as an unusual negative feeling, which can be a combination of sadness, anxiety, a feeling of "fatality" with a loss of interest in certain aspects of one's life. In concrete terms, a study (Boujut, Koleck, Bruchon-Schweitzer and Bourgeois. 2009) shows that this feeling of ill-being can lead to emotional distress, depressive symptoms, suicidal thoughts, a feeling of loneliness, stress, anxiety (strongly related to work and academic success, as well as time and money), obsessive-compulsive disorder or substance abuse. Another study (Gosselin and Ducharme 2017) identifies more precisely the main factors of student distress and anxiety. Distress can be triggered by fatigue or exhaustion, academic pressure, family conflict. The three most frequent symptoms of anxiety were the feeling of not being capable, the fear of failing and the fear of disappointing.

When students use the help available for their mental health, their anxiety symptoms decrease. However, the usage of support is influenced by existing bias about mental health, that reduce students' willingness to seek help.

According to the World Health Organization (WHO), mental health is "a state of well-being that enables people to achieve their potential, cope with the normal challenges of life, work successfully and productively, and be able to contribute to the community". Mental health is determined by many factors: socio-economic, biological, and environmental, including the working environment. Working conditions are indeed an important determinant of mental health.

It has also been shown that epidemics contribute to the deterioration of mental health. Students are identified as a part of the population that is particularly vulnerable to anxiety, depression, stress...

1.2 Aim and questions

Faced with this problem in their daily lives, student engineers decided to write an article on the mental health of students in engineering schools. To do this, we built a survey:

- to measure whether this is a reality in our school and on what scale.
- to evaluate the perceived impact of studies on students' well-being.
- to identify measures that have a positive impact on students' mental health.

2 METHODOLOGY

An online survey was submitted in May 2023 to all students of EPF, a general engineering school. Data were collected during a week holiday, specifying their home campus (Cachan, Montpellier or Troyes), their year of training (from the first to the fifth-year post-bac) and their gender.

The survey included both closed and open questions: 16 questions on students' general well-being, 4 questions on the perceived impact of their studies on their ill-being, 6 questions on mental health support and awareness.

3 RESULTS

Our final sample consisted of 185 responses: 85 students from Cachan, 73 from Montpellier and 27 from Troyes. We wanted to obtain representative samples from each campus because student support and infrastructures are not the same for the different campuses.

Our sample is composed of 109 men, 71 women and 5 not defined. We'll take an interest in comparing results between our men and women samples.

The five years of engineering studies are divided into two cycles. The 3-year Bachelor cycle includes two years of preparatory classes. The last 2 years (Master cycle) are devoted to one major of the nine proposed by EPF for one half and internships for the other half. 77% of the respondents to the survey are Bachelor students (143 students), the remaining are Master students (42 students). In the same way we'll compare results between the different academic years, to study the impact on mental health.

3.1 Sense of belonging

The first questions of the survey deal with the students' feeling of belonging to their environment: whether they feel they belong at school, then in their class and finally whether they feel surrounded and supported overall. Students feel that they belong in the school (77% "Totally agree" and "Agree") and in their year group (87%). Students globally feel supported and surrounded (75%). There is a disparity between campuses on this question: from 60% to 83%. Few students (5%) answered "Disagree" or "Strongly disagree" to the three questions. The students who responded to the survey generally feel that they belong at school.

3.2 Ill-being

Despite this feeling of belonging, 68% of the students interviewed answered "Yes" to the question "Have you experienced periods of ill-being during this school year?". 60% of respondents identifying as men experienced periods of ill-being during the school year. This proportion rises to 78% when respondents identify as women. Regarding the academic year, the percentage is similar for all years: about 2/3 of the respondents experienced periods of ill-being during the academic year and this reaches 80% for 2nd year students. There is also a disparity depending on the campus: from 64% to 75%.

This highlights the fact that considering the mental health of students in an engineering school is not limited to their overall sense of belonging. It is also necessary to provide support during periods of ill-being, even if they feel well for most of the year, particularly regarding the consequences of these periods.

Indeed, different consequences of ill-being were then proposed to the students who answered "Yes" (Fig. 1). We note that among these students: 63% have altered the quality or quantity of their sleep, 55% became isolated, 55% could no longer concentrate, 36% changed their eating habits, 30% could no longer manage their daily lives, 15% had suicidal thoughts, 14% had an addictive behaviour, 9% had harmed themselves.

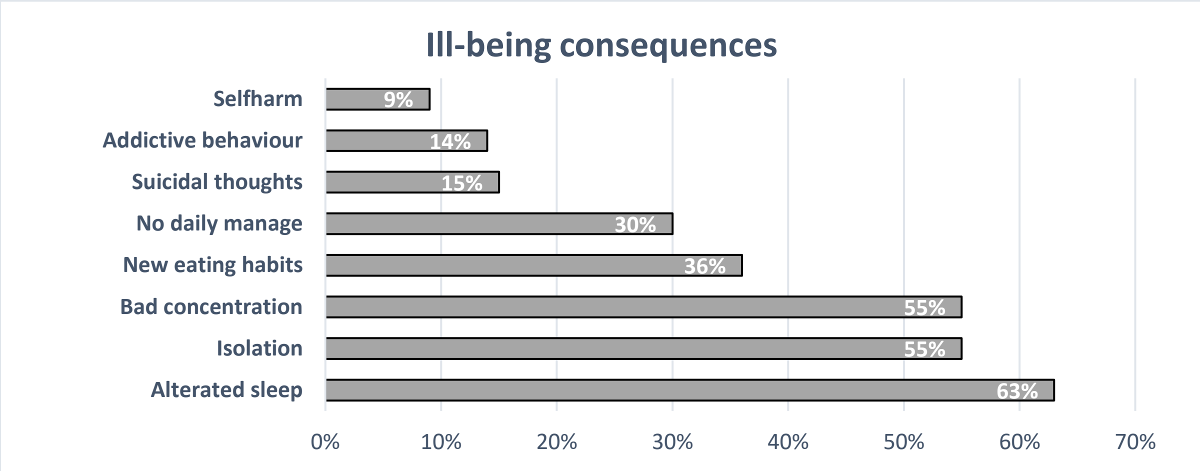

Fig. 1. Consequences of ill-being on students

70% of students who experienced ill-being felt that it was accentuated by their studies.

3.3 Stress

In the collective imagination, student ill-being is often associated with, or even equated with, stress related to academic pressure. We asked students to evaluate their stress level on a scale from 0 (no stress) to 10 (absolute unbearable stress). Levels 4 and 5 are average stress. Level 6 and beyond correspond to high stress.

When the question of stress is raised in our survey, we obtain (Fig. 2.):

- Exam period stress of 5.62/10 on average.
- Academic stress (excluding assessments) of 4.35/10 on average.
- Extracurricular stress of 4.16/10 on average.

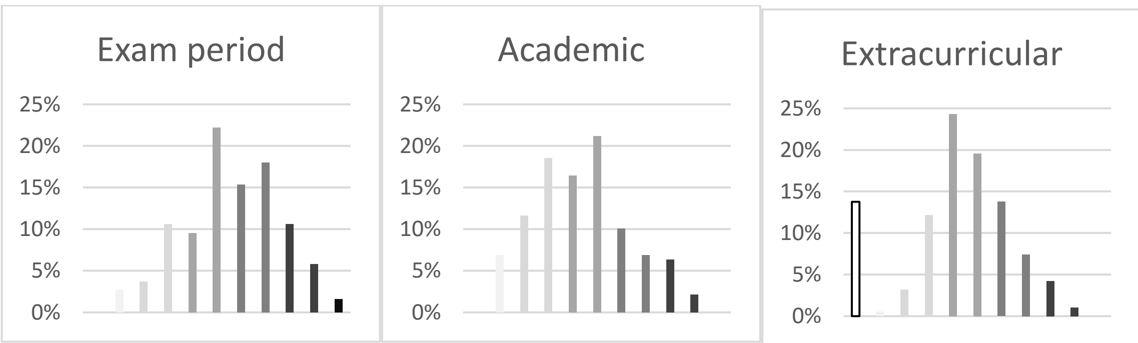

Fig. 2 Students' stress level (from 0 to 10 from left to right) distribution during (a) exam period, (b) academic time and (c) extracurricular time

Students were asked about the main stressors in their studies. The most common answer is "exams and projects reports". More surprisingly, it's not the difficulty of the work that is mentioned next, but the time management. Indeed, the overlapping of different exams and reports deadlines on certain weeks are difficult to manage for students. This feeling of accumulation and lack of time to do everything is very much mentioned in the feedback. Late submission of grades is also a source of stress for students. Sometimes, they're uncertain until the end of the semester whether they will pass a course without having to retake it. Another source of stress mentioned is the relationship between students (especially during group work), but also between students and teachers (lack of availability, poor communication, arbitrary group choices). Finally, fear of failure, school fees, and future career choices cause stress.

3.4 Talking about mental health

Whilst approximately 68% of students have experienced ill-being during the academic year.

This ill-being is not necessarily communicated by the respondents. Half of them (48%) feel the need to hide their mental state at school. However, only 18% of them felt that communicating about their mental health had a negative impact on social relations at school. We observe a discrepancy between students' overall opinion on communicating their mental health and their actions.

3.5 Ill-being consequences

We decide to look at whether the ill-being of men and women is expressed in the same way. Respondents who had faced periods of ill-being identified the behaviors in which they recognized themselves. Women seem to be prone to ill-being more than men and to suffer more consequences: we have 5 consequences concerning more than 30% of our women sample against only 3 for our men sample (Fig. 3). Some consequences such as eating disorders affect women more than twice as men, while men seem to be more prone to addictions.

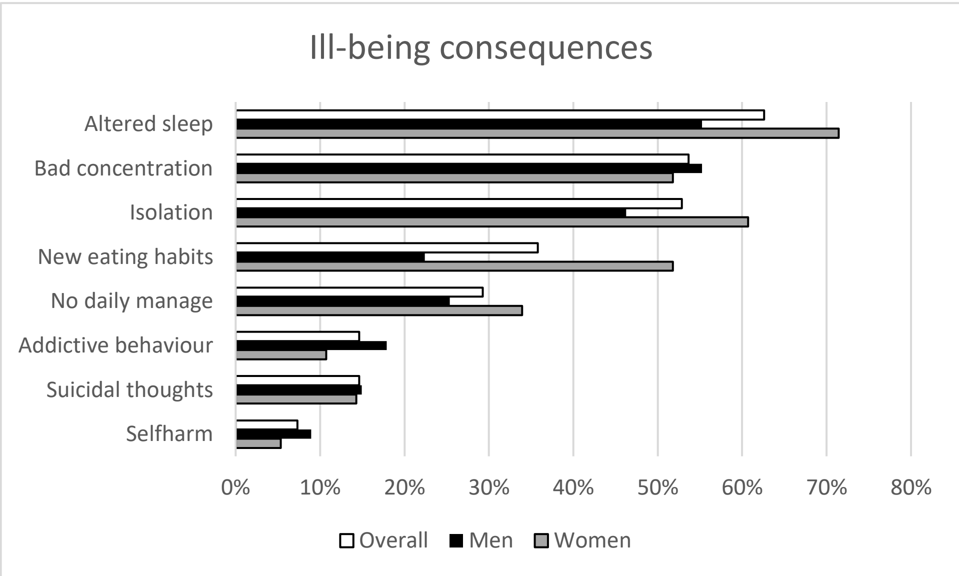

Fig. 3. Consequences of ill-being on men and women

3.6 Improving the consideration of mental health

Students' lack of communication about their mental health can also be explained by their lack of knowledge of the services provided by the school: 64% of respondents felt that they were not aware of the services offered by the school. Depending on the campus, the lack of knowledge goes from 43% to 77%.

More generally, 55% of the respondents did not feel sufficiently informed about the existing programs.

Different activities and support services were suggested to the students. They were asked to identify from a list which ones they could apply for. Students voted for the following solutions (Fig. 4.). As relaxation is the most popular answer, this highlights the importance of reducing the stress felt by student.

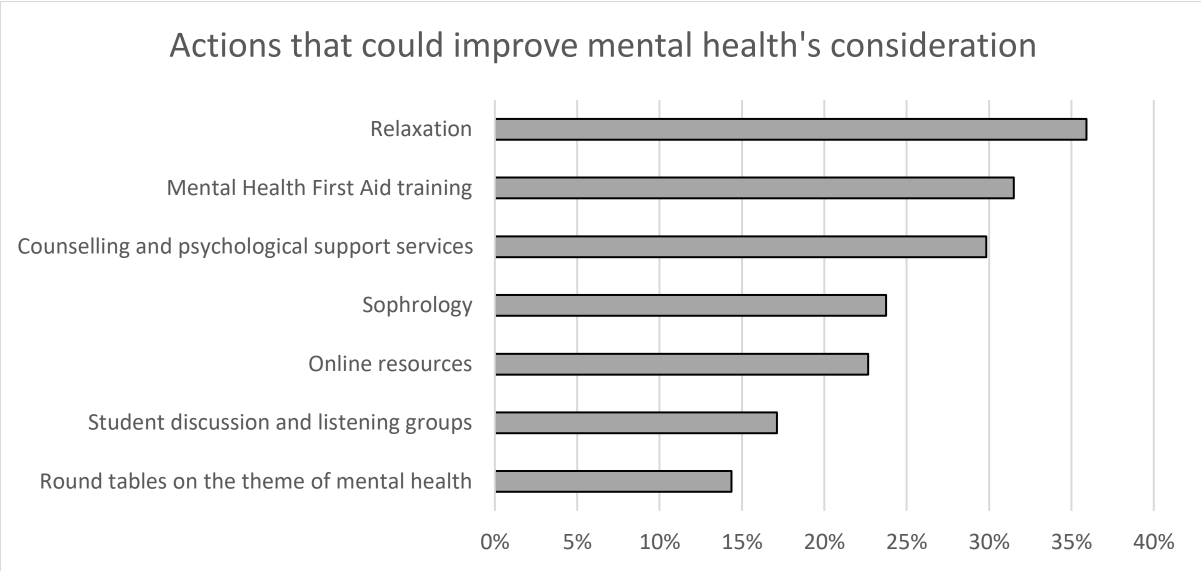

Fig. 4. Solutions to improve mental health's consideration.

Besides these solutions the students asked for more sensibilization actions concerning mental health, to change how the subject is seen by teachers and administration's members. They'd like to have a place, or a school organization dedicated to mental health.

4 SUMMARY AND ACKNOWLEDGMENTS

The survey and this study assessed the mental health of students, identified stressors that the school can act on, and suggested ways to improve the consideration of mental health. Our specific comparisons show that ill-being is present in every study year of an engineering school. Solutions to improve students' mental health must consider the different types of work required of students. Besides, women seem to be particularly affected, it is also to be considered when thinking about solutions.

One of the positive aspects of this work is that it has allowed mental health to be talked about more freely in the school and to show that it is an important issue. It is planned to continue this study next year by collaborating with faculties of psychology and education. It will also be useful to compare and discuss the specific context of engineering student with the work of Jensen (Jensen and Cross 2019), (Jensen et al. 2023). This study indicates that many students perceived high stress and poor mental health to be normal and expected in engineering.

We would like to thank all the students who responded to this survey, as well as all the people who supported this project, including M-P. Cuminal, DEI officer and F. Stephan, campus director.

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CAN DESIGNING FOR MARS STIMULATE US TO THINK MORE SUSTAINABLY FOR EARTH?

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ABSTRACT

This work describes the use of an arts-based project to stimulate creative thinking about design and sustainability for engineering students of all disciplines and years. ‘Building a Martian House’ was a public art project where a house designed for Mars was built in the centre of the city of Bristol, UK. It was conceived by artists, designed by the public, architects and engineers and built by construction companies. In this work, a workshop for students was developed and run based on this art project. Its aim was to use the challenge of designing for Mars as a provocation to thinking about sustainability in designing for Earth. This workshop was run for two hours for thirty-five students from different years and disciplines and involved two exercises to stimulate creativity. Students completed a pre-and post-workshop questionnaire as feedback. An important part of the workshop was the viewing of an exhibition of sixty images from the Martian house project. These images covered the design, development and building process of the Martian house and artefacts within it. Feedback from the questionnaires indicated that the workshop fulfilled some of the aims, it was interactive and guided, offered teamwork and independent design opportunities and provoked thoughts about resource utilisation and sustainable design.

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1 INTRODUCTION

1.1 Background to the project

The ability to think creatively is essential for surviving and adapting to the world's rapid technological, economic, social, and global changes (Beghetto, 2015). Previous work has established the use of arts to increase creativity in engineering courses: "*Bring in the arts and get the creativity for free*" (Csikszentmihalyi, 1996) and an arts-based instructional model for student creativity in engineering suggested: "*exposing engineering students to different ways of thinking is essential for growth in creativity*" (Laduca *et al.*, 2017). Recent literature has covered the types, forms and conditions of learning and characterising knowledge and the artistic experience (Morari, 2023). In other work creativity has been defined as the capacity to create novel ideas, acts, or products that alter existing domains or turn existing domains into novel ones (Styhre and Eriksson, 2008). Asking students to design for a completely novel context and environment could therefore hopefully stimulate their creativity. The aim of this educational project was to use an arts-based project as a springboard to encourage students to gain new perspectives on engineering design for Earth and sustainability. This would be achieved by them participating in a workshop and viewing an exhibition which uses the 'Building a Martian House' arts project (https://buildingamartianhouse.com/) as inspiration.

In August 2022 a Martian House was built as a public art project on the harbourside of the city of Bristol, UK. This explored how a home for life on another planet might be designed. Mars is a place with a harsh environment and limited resources – no air, low pressure, little sunlight, cold and high levels of radiation. It was hoped that designing within these constraints and imagining how a small community would live on Mars would stimulate students to think more about building and living sustainably on Earth. The Martian house started as an idea seven years ago and progressed through workshops, designs, architectural drawings, construction plans, build and opening to the public (see Fig 1 and 2). It was hoped that many of the assets (photos, drawings and artefacts) developed could be shared with students. This would be achieved as part of an installation which would take viewers on a journey through the project asking key questions about reuse of materials along the way. This was a unique opportunity to use this remarkable project as a provocation to learn. Another goal was to bring innovative ways of thinking about sustainability and resource use into the curriculum, as mandated by new UK Engineering Council accreditation guidelines (called 'AHEP4').

This paper covers the background to the work and the Martian House project in section 1, then section 2 outlines the workshop developed for the students, along with both pre- and post-workshop questionnaires put to the students and how the exhibition was developed. Section 3 describes the results of the questionnaires whilst section 4 is a discussion of the work and its limitations. This leads onto some suggestions for further work in section 5, with recommendations in section 6 and conclusions in section 7.

Fig. 1. The Martian House on Bristol's dockside (exterior)

Fig. 2. The Martian House (interior)

2 METHODOLOGY

2.1 Workshop

The workshop was run for undergraduate engineering students from first to fourth year and all engineering disciplines. At the University of Bristol, the disciplines include Mechanical, Civil, Aerospace, Computing, Electronic, Engineering Design and Engineering mathematics. It was advertised through year group lists and through student societies and quickly reached the capped capacity of fifty participants. The authors decided to use a voluntary extra-curricular two hour-long workshop to engage students. This was for several reasons, firstly, it offered a way for the students to engage in creative activities in small groups which would encourage teamwork and facilitated working across disciplines and year groups, secondly it mirrored the process used in the design of the Martian House and, thirdly, it was flexible to the unpredictable numbers. The format of the workshop is illustrated in Table 1:

Table 1. Workshop activity details

Time	Type of Activity	Activity details
2 days before	Student completes	Pre-workshop questionnaire is sent out
20mins	Authors talking to slides	Introduction to Martian Environment, introduction to previous Martian habitat experiments, explanation of design process
15mins	Students creating	Challenge questions: What are the essentials needed to live on Mars? What resources do you think are available on Mars? Make a list.
10mins	Students report back	Joint list of essentials and resources is made
40mins	Students creating	Choose an essential item you'd like to design. Using your list of available resources, explore how you might design your item with what is available. Make a rough design - paper sketch or digital.

10mins	Students report back	Each group presents their design which they have sketched on a large piece of paper
10mins	Authors talking to slides	The artists talk about the design process for the Martian House, its features and ethos.
10mins	Students walking and looking	Students view exhibition as they exit the workshop
Later	Student completes	Post-workshop questionnaire is sent out

This involved a mix of introducing the topic to the students, then allowing them to be creative by working on two lots of challenge questions together. After each of the two lots of working together, they reported back to the whole group. Group size was four to five people in size to promote teamwork and groups were composed of mixed disciplines and year groups. At the end of the workshop, the artists gave a brief description of the design process for the Martian House, its features, including artefacts within the house, but also the ethos of the project.

2.2 Questionnaire

To understand the effectiveness of the workshop, an anonymous pre- and post-workshop questionnaire was devised. The questionnaires received approval from the Faculty Ethics committee before being deployed (Ethics application no.14027). The questionnaires were deployed digitally via link and QR code and sought permission from the participants to be published. These were deployed a few days before the workshop. The post-workshop questionnaire was deployed straight after the workshop.

2.3 Exhibition

Over the seven years that the Martian House project has been in development, there has been a strong focus on visual storytelling. This has included having an artist capture early workshops, the architect creating rendered moving images for a summer open-access activity at the 'We the Curious' science museum and having the final Martian house build and subsequent use captured by a professional photographer and subsequently turned into a short documentary (https://www.youtube.com/watch?v=Migiyq7QxPc). As well as the artists themselves keeping a rich visual record of their work. As a result, it was decided to bring into the workshop a visual narrative element, in the form of a photo exhibition, on the way out of the room where we held the workshop. The reason for doing this, beyond sharing the story with workshop attendees, was to create a visual legacy of the project for other learners to engage with, in line with the 'LEaRN' approach where "all spaces should be considered learning spaces", even, in this case, corridors! (Taylor, 2019)

The exhibition was set up by collating a wide variety of different outputs from the Martian house project and laying them out in a large space chronologically. The artists then selected the most appropriate images, and added five statement-based posters, which captured the essence of the project: “It takes seven months to get to Mars.” “Everything you own will be important.” “You’ll need to fix everything when it breaks.” “Suddenly your rubbish becomes something you might need.” “Can designing for Mars give us the perspective we need for living on Earth?” The students examined the exhibition on the way in and out of the workshop.

3 RESULTS

3.1 Pre workshop questionnaire

Thirty responses out of thirty-five attendees were received to the pre-workshop questionnaire. The first question asked how much the students already knew about three different aspects: design for Mars, design processes and design for sustainability. Figure 3 shows the results for this first question.

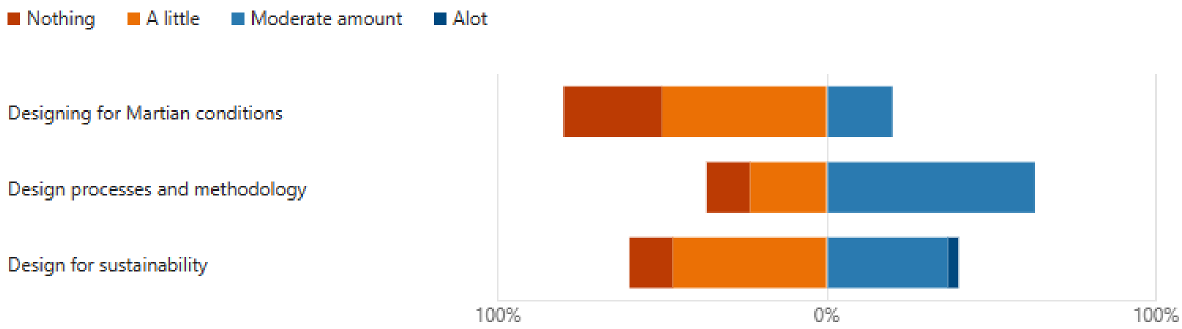

Figure 3: The results of the question: How much do you know about…? (n=30)

This illustrates that the area that the students thought that they were least knowledgeable about was designing for Martian conditions (with 30% knowing nothing and 50% knowing a little). More of them were happy with design processes (with 63% saying that they were moderately confident) but 47% said they knew only a little about design for sustainability.

In reply to the question: what do you hope to get from the workshop? 67% of respondents replied with some variation on ‘Discover more about Mars habitats’, whilst 20% replied with some variation on ‘More knowledge and fun’.

3.2 Post workshop questionnaire

Twenty-six responses (out of thirty-five attendees) were received in response to the post-workshop questionnaire.

In response to the question ‘has the workshop changed how you might think about designing for Earth?’, all participants answered either Yes (50%) or Maybe (50%). When asked to explain this answer, 70% of the response were variations on “*we need to use the resources available to us more deliberately*”, and “*the focus on designing with limited resources could be easily applicable to Earth*”. In contrast, one student pointed out *"I don't think there'll be acceptance on Earth for the basic living style on Mars*" and another very practically said: "*It personally has made me want to design a hydro/aeroponic system to use at home…*".

In response to the question 'How much more do you know about…", 92% of students felt that they had learned at least a bit more about designing for Martian conditions, 85% said that they had learned at least a bit more about design for sustainability, then 81% said that they had learned at least a bit more about design processes.

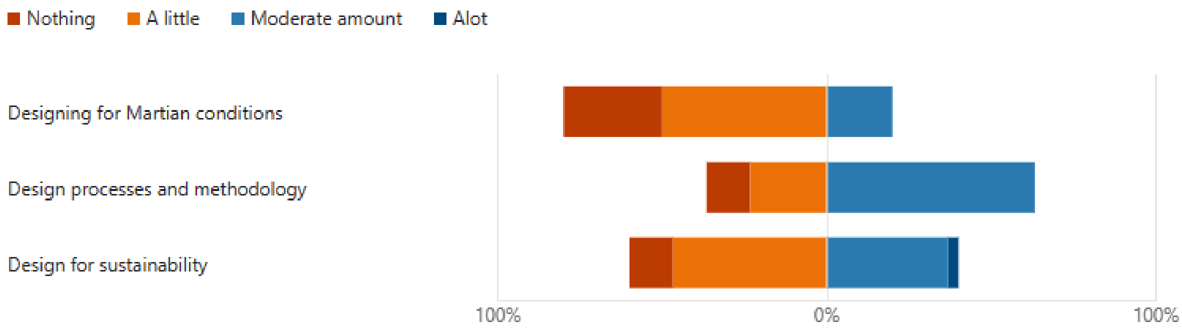

Figure 4: Responses to the question: 'How much more do you know about…" (n=26)

In response to the question 'What did you enjoy about the workshop?', students mentioned "*Good mix of independent work and being told stuff*", but also "*the freedom to think creatively*" and "*the atmosphere was great*". Several students also mentioned "*working in teams*".

In response to the question 'What would you change about the workshop?', students suggested "*maybe snacks*" (!), 20% said "*make it more technical*", 20% said "*more guidance on the design*" and 12% said "*more on sustainability*". In response to 'any more comments?' there were few responses mostly expressing thanks. There was one comment on the exhibition: '*Interesting exhibition*'.

4 DISCUSSION

This work has used an arts-based project as a provocation to creativity in design and thinking about sustainability. There were many limitations to this research. Only one two-hour-long workshop with thirty-five students has been run up until now, so the results are necessarily preliminary. It is challenging to measure how successful this was from questionnaires with just a few questions, the number of students responding were thirty and twenty-six for the pre- and post-workshop questionnaires, which mean that the sample size was small. As the responses to the two questionnaires were anonymous, it was not possible to know if the same people answered both the questionnaires, so it was hard to compare the answers. However, it appeared from the data so far, that the workshop did encourage the students to change how they might think about designing for Earth and that most of them learned at least a bit more about designing for Martian conditions, the design process and design for sustainability. Interestingly, and perhaps not surprisingly, their response to ‘how much more do you know about…?’ was a mirror image of their response to ‘how much do you know about…?’. It is debatable whether people are a good judge generally of what they think that they have learned. In addition, whether what students **think** they want to learn is not necessarily the same as what they **will** learn.

With a short exercise such as this, it was not surprising that the students requested more technical information and more guidance. Indeed, the request for more technical information indicates that they are emphasising technical aspects instead of staying in the creative space. More information could be made available, but there is also never enough information! As authors, we wonder if we should push in the opposite direction, to encourage more integration of the arts/social aspect. We could encourage the students to go beyond their technical training: how does an artist approach? Some of the questions in the original Martian House project included: “Can designing for Mars give us the perspective we need for living on Earth?” and “How can we live well on Mars?” From the feedback it appeared that the format of the workshop with a mix of disciplines and years worked well for the students.

5 FURTHER WORK

Eventually it is intended to turn the workshop into a session within the first year Engineering Design unit which is taken by six hundred students across the faculty. One of the learning outcomes for this design unit is to help students see the interrelationship between society and engineering and to encourage thinking about sustainability. Ideally, the workshop would encourage students to critically examine their assumptions, values, and biases and reflect on how these factors influence their engineering practice. Whilst we have attempted to measure the impact from a short workshop on the participants, it would also be interesting to explore our own journey, having been active participants in the artwork.

6 RECOMMENDATIONS

The authors’ thoughts on recommendations from this work are as follows:

1. Arts-based projects can stimulate creativity in engineering and lead to a surprising amount of learning.
2. Unexpected contexts can offer new perspectives on challenging problems.
3. Mixing the students in terms of disciplines and years worked well and led to a good atmosphere.
4. Students will tend to ask for more and more technical information but can be encouraged to stay in ‘uncertainty’ and the creative space.
5. Workshops should include explicit opportunities for student reflection, self-assessment, and self-awareness. Reflection prompts, journals, and group discussions may be used to facilitate this process.
6. When exploring an education project, it is interesting for the practitioner to ask how being involved may impact on their own work, thoughts and biases.

7. Artefacts made during an arts-based project can add to an engineering education context.

7 CONCLUSIONS

This paper describes the use of an arts-based project to build a Martian House to stimulate creativity for engineering students in thinking about designing for Earth. A workshop for students was developed and run with the aim of using the challenge of designing for Mars as a provocation to thinking about sustainability in designing for Earth. Thirty-five students attended the workshop and feedback was collected. An exhibition showing images of the design process for the Martian house was set up along the corridor to the venue and formed part of the workshop. The feedback indicated that whilst the format of the workshop worked well and almost all the students felt that they had learned at least a bit more about the areas covered, a percentage of the students wanted more technical information and guidance. Further work will involve incorporating the workshop into an Engineering design unit in the common first year of Mechanical, Civil and Aerospace Engineering degrees.

8 ACKNOWLEDGMENTS

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DIGITAL LEARNING RESOURCES, HYBRID TEACHING AND REMOTE STUDENTS - ARE OUR STUDENTS ACTIVELY ENGAGED?

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***Conference Key Areas**: Virtual and Remote education in a post Covid world, Fundamentals of Engineering: Mathematics and the Sciences*
***Keywords**: Blended learning; hybrid teaching; learning pathways; statistics*

ABSTRACT

At the Norwegian University of Science and Technology, a new cross-campus statistics course for approximately 1000 engineering students was planned for the fall of 2020. Due to the pandemic, digital learning resources were developed to allow students to work from home or campus, individually or collaboratively. These resources include short learning videos, automatically graded exercise sets, and Jupyter Notebooks for Python coding. Since 2020, digital learning resources have been essential for teaching statistics to engineering students across three campuses, and remotely. To help students navigate digital resources, on-campus activities, and assessments, each week of the semester was structured according to specific learning paths. However, asking the students to watch videos and work on exercises before on-campus or digital lectures is no guarantee that they will do so. For this study, we use video and assessment statistics, along with survey results, to determine to what extent the proposed learning paths were followed and the

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perceived usefulness of the various elements that make up a learning path. In surveys, the engineering students at the Norwegian University of Science and Technology report great satisfaction with videos and digital assignments (along with scaffolding exercises) in the statistics course. By utilising digital user statistics, we observe patterns of engagement with digital resources that are closely tied to the proposed learning paths.

1 INTRODUCTION

1.1 Background: A new statistics course in the middle of a pandemic

In 2016, the Norwegian University of Science and Technology (NTNU) merged with three Norwegian colleges. Therefore, NTNU now offers bachelor engineering programs in three different counties, with many basic courses running in parallel across three campuses. The statistics group at the Department of Mathematical Sciences has since 2020 been offering the mandatory third semester undergraduate statistics course (7.5 ECTs). This course covers well-known topics such as probability and probability distributions, reliability, descriptive statistics, and basic statistical inference. In addition, the students complete one module relevant for engineering applications; design of experiments and statistical process control; measurement error and error propagation; or data science and statistical learning. Approximately 1000 engineering students from 12 different study programs enrol in this course annually (some programs also offering remote studies).

In the fall of 2020, a new team of lectures located across the three campuses were to develop and teach this cross-campus statistics course for engineers for the first time. Due to the ongoing pandemic and social restrictions, we had to plan for a completely digital off-campus learning environment. Geographical and multicampus challenges then being erased, the team decided to avoid giving parallel digital 'local' lectures. Instead, we could take on different development tasks; developing short learning videos (5-15 min) as a way of introducing new material to the students; giving a complementary digital session with worked examples; developing weekly digital quizzes; and preparing material for the various project modules. Despite a challenging and hectic semester, we were left with the overall impression that we had developed a resource bank and a way of coordinating teaching that could benefit both the students and us. Since then, we have built a blended learning environment for hybrid cross-campus (and remote) teaching. We *intend* our students to watch learning videos at the beginning of the week (especially before they attend the mid-week campus-based lectures), and we *suggest* that they start working on the weekly assignments early so that they manage to finish in time for the Friday evening deadline. Now we ask ourselves, are our students actively engaged?

1.2 Motivation: Blended learning

The motivation behind this paper is twofold. First, we present a post-covid blended learning environment in statistics for engineering students. As a definition of blended learning, we adopt the following definition of Boelens et al. (2015): "…*learning that* *happens in an instructional context which is characterized by a deliberate combination of online and classroom-based interventions to instigate and support learning*”. A shift from mainly classroom-based instruction to digital resources can foster students’ control of their own education in terms of mode and pace of learning (Castro 2019). Furthermore, differentiated modes of instruction and learning materials can be valuable for heterogeneous student groups (Boelens et al. 2018), also in terms of living circumstances (Guppy 2021). In an engineering mathematics course, Liestøl (2020) found that students often waited until the last day before assignments to watch videos and skipping videos considered less important or too lengthy. As students may show up unprepared for in-class sessions if the required pre-class workload is too high the length of learning videos is typically recommended to be 6-9 minutes (Guo et al. 2014) or 12-20 minutes (Lagerstrom et al. 2015). For this study, we will compare data from the two ‘post-covid’ semesters fall 2021 and fall 2022, focusing on the engagement (both overall use and time of use) with learning videos and digital assignments. Our aim is to gain insight into students’ engagement with digital resources.

2 THE COURSE

2.1 Course content and structure

This paper concerns students’ engagement with digital learning resources during the first nine weeks of the statistics course for engineers at NTNU. This part of the course is assessed with an individual digital exam that counts towards 70% of the final grade (the remaining 30% of the grade is based on a group project in one of three optional modules). Each week is defined by a specific topic: 1. Descriptive statistics; 2. Probability of events; 3. Stochastic variables; 4. The binomial distribution; 5. Poisson processes and reliability; 6. The normal distribution; 7. Estimation and confidence intervals; 8. Hypothesis testing; 9. Simple linear regression. For each topic (and therefore each week) we have developed 3-4 short learning videos; a catalogue of in-depth examples for campus-based sessions; Jupyter Notebooks with worked data examples in Python; and digital assignments. The students are required to pass (i.e., at least 8 out of 10 points) at least 6 of these weekly assignments, while all other activities during these first nine weeks are voluntary. We offer both on-line and on-campus tutoring each week. The digital exam questions are of a similar type as the quizzes, but without access to other tools than calculators and formula sheets.

2.2 Weekly learning paths

For each topic (and week) we present the students with a recommended learning path, see Figure 1 for a generic representation. We recommend that the students watch the learning videos and attend the 45 min digital cross-campus plenary overview lecture in the beginning of the week, and especially before attending the mid-week campus lecture. The campus lecturer organises this session based on the assumption that the students have watched the videos. The deadline for the weekly assignments is at the end of the week, but we recommend that the students start out early (the first few exercises are always at an introductory ‘get-started’ level). All materials and information necessary to complete a topic become available to our students in our ELS (Blackboard) on the Friday prior to week in question.

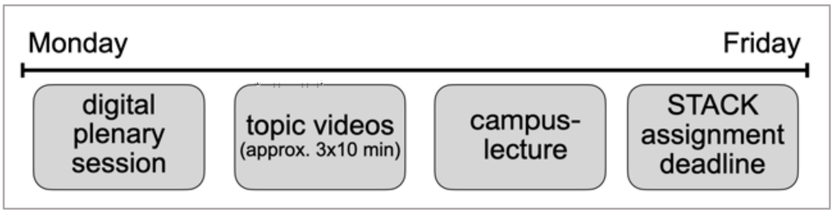

Figure 1. Weekly learning path

2.3 Learning videos, Jupyter Notebooks and assignments in STACK

Our learning videos are hosted in Panopto, one folder for each week, three or four videos per topic. The videos are based on animated Keynote presentations where the lecturer introduces the main concepts of the topic. The length of each video is between 5 and 15 minutes. Python is the preferred programming language for the engineering programs at NTNU, and therefore also used for data analysis and computations in the statistics course. Any data analysis presented in a video may be reproduced by our students by interacting with the corresponding Jupyter Notebook. Notebooks for generic calculations with probability distributions are also available to them. Each week, the students are also given a digital assignment created with the STACK question type in Moodle. For each question, all students get a similar statistical problem to solve, but the numbers (and therefore also the answers) are random and individual. We encourage collaboration on methods, but each student must submit his or her individual calculation. We have also developed corresponding step-by-step scaffolding exercises in STACK so that the students may check intermediate calculations and get tips on how to proceed. Some of the weekly exercises guide the students to a Jupyter Notebook where they must edit and run code and report an output back into the STACK-assignment.

2.4 A (subtle) change between two semesters

For historical reasons, we started teaching this course with a one-week delayed deadline for assignments. The learning path presented in Figure 1 was promoted by lecturers in 2021, but the actual assignment deadline was in fact one week later. During that semester, local lecturers observed that students tended to be behind with their work, so that the weekly campus lecture made no sense to them. For 2022 it was therefore decided to give the students a much tighter deadline (see Figure 1).

3 METHODOLOGY

For this study, we use anonymous video and assignment statistics to determine to what extent the proposed learning paths were followed in 2021 and 2022. We also present anonymous survey results regarding the perceived usefulness of the various elements that make up a learning path. Video statistics were downloaded from the platform Panopto where the videos are hosted. We used the count of all viewings of length greater than four minutes as an estimate of the number of students watching a certain video. Averages were taken over the number of videos for each week (3 or 4). The exam period was not considered. For the assignments in STACK we report the weekly number of attempts as well as the start day of these attempts. In both 2021 and 2022 an anonymous survey was sent to all students, the response rate being approximately 22% in 2021 and 32% in 2022. In both surveys, students' perceived learning outcomes from various learning resources were reported. The results of the data analysis are presented in Section 4, while a discussion of our findings is given in Section 5. Data visualisation was performed using ggridges (Wilke, 2022) for ggplot2 (Wickham, 2016) in R (R Core Team, 2022).

4 RESULTS

4.1 Assignments in STACK

In Table 1 we present the number of attempts for the weekly assignments. The number of attempts for the first assignment is taken as an estimate of the number of students following the course. In both 2021 and 2022, the number of attempts was above 90% throughout the first six weeks, before it dropped to nearly 60% for the ninth topic. The required test score was 8 out of 10, and in terms of average scores we observe a decline towards last weeks, but no notable differences between the two years.

Table 1. The number of attempts per exercise set (assignment) in STACK (exam period excluded) as well as the average total score (out of maximum 10) and corresponding standard deviation (SD). Percentages are based on the number of views relative to the estimated number of active students (1147 in 2021, 1076 in 2022).

Topic	1	2	3	4	5	6	7	8	9
2021	1147 (100%)	1106 (96%)	1094 (95%)	1098 (96%)	1102 (96%)	1077 (94%)	975 (83%)	863 (75%)	704 (61%)
Score (SD)	8.9 (1.9)	8.9 (1.7)	8.7 (1.7)	8.9 (2.0)	8.5 (2.2)	8.2 (2.1)	7.9 (2.8)	7.5 (3.4)	7.4 (3.4)
2022	1076 (100%)	1056 (98%)	1044 (97%)	1037 (96%)	1022 (95%)	999 (93%)	931 (87%)	798 (74%)	677 (63%)
Score (SD)	9.0 (1.4)	8.6 (2.0)	8.6 (1.7)	8.8 (2.1)	8.6 (1.9)	8.3 (1.8)	7.9 (2.7)	7.2 (3.3)	7.6 (3.1)

In Figure 2 we present frequencies of starting dates for the weekly assignments. Here, we observe a substantial difference in student behaviour between the two semesters. In 2022 most students started the assignment on Mondays. In 2021 however, we observe two 'modes' of student behaviour. Approximately half (or even less) of the students started working on the assignments in the intended week (uniformly spread out between Monday and Friday), while the other half postponed the exercise set until the following week, i.e., the week of the deadline.

In 2022 there are two additional observations to be made. Prior to week 7 and 8, some students reached out to us regarding taking an autumn break (in line with the

Norwegian school holidays) and requested learning materials to be published one week prior to the schedule. The work of these students can be seen as an early peak in weeks 7 and 8. Furthermore, because some students have side-jobs during the week, they requested the deadline to be moved from Friday to Sunday so that they could use Sundays to catch up on their studies. This delay can be seen in Figure 2 (2022) for weeks 8 and 9.

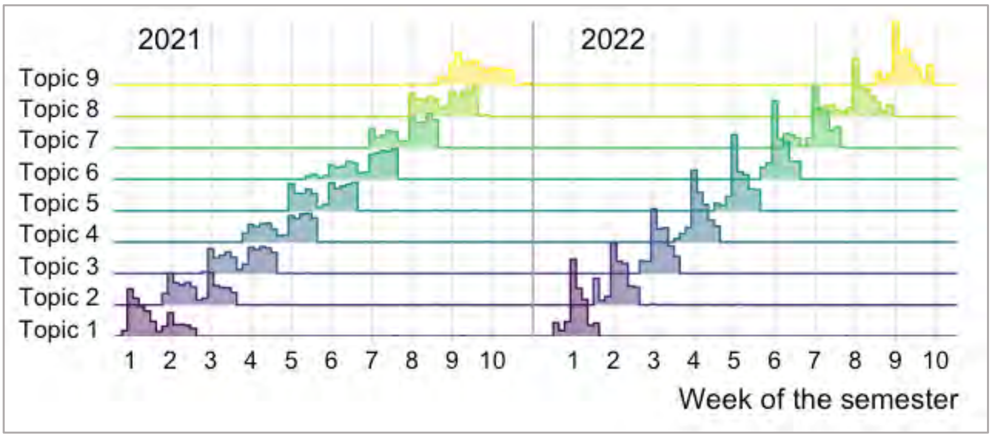

Figure 2. Frequencies of starting dates for weekly STACK assignments in 2021 and 2022, comparing starting dates per topic between the two semesters. Monday is the first day of each week (grey vertical lines). In 2021, exercises were made available the Friday before the topic was covered and the deadline was Friday two weeks later. In 2022, exercises were similarly made available the Friday before and the deadline was Friday one week later.

4.2 Learning videos

Video view counts per topic (1-9) are presented in Table 2. By assuming that few students watched substantial proportions of each video more than once (not counting the exam period) and that few students watched videos in groups, these numbers can be taken as estimates of the number of students engaging with this digital resource. We observe that between 70% and 80% of students watched learning videos each week, but with a drop in view counts towards the end which follows the same trend as for the assignments (Table 1).

Table 2. The average number of views (at least 4 minutes) per video for each topic in the fall semesters of 2021 and 2022 (exam period excluded). Percentages are based on the number of views relative to the estimated number of active students (1147 in 2021, 1076 in 2022).

Topic	1	2	3	4	5	6	7	8	9
2021	1043 (91%)	978 (85%)	1015 (89%)	860 (75%)	827 (72%)	884 (77%)	782 (68%)	901 (79%)	788 (69%)
2022	813 (76%)	917 (85%)	843 (78%)	841 (78%)	780 (73%)	797 (74%)	750 (70%)	796 (74%)	557 (52%)

In Figure 3 we present frequencies of video viewings for the nine topics, comparing each topic between the semesters of 2021 and 2022. We see a trend that is very similar to that of the assignments (Figure 2). In 2022 most students watched videos on Mondays (thereafter Tuesday and Wednesday), while in 2021 we again observe two 'modes' of student behaviour; approximately half of the students followed the intended schedule, while the other half was delayed by one week.

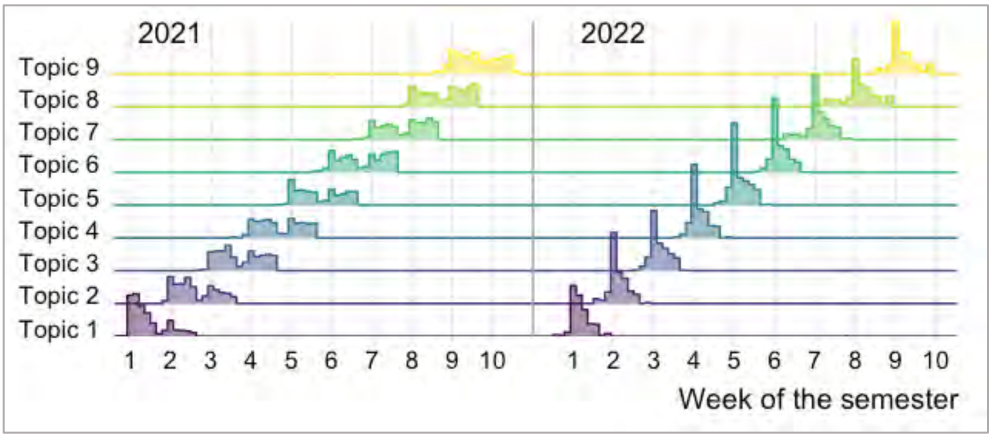

Figure 3. Frequencies of video viewings in 2021 and 2022, comparing dates per topic between the two semesters. Monday is the first day of each week (grey vertical lines).

4.3 Survey results

In 2021, students were asked to select the top four (out of thirteen) learning resources for their (perceived) learning outcome. Out of 251 respondents, 89.2% selected the STACK assignments, 74.1% selected the learning videos, 54.2% selected previous exam questions, and 52.2% selected the STACK step-by-step scaffolding exercises. Only 8% of respondents rated the Jupyter Notebooks top four. The digital plenary lectures, campus lectures and textbook were selected among top four resources by 14.3%, 12.7% and 14.3% of respondents, respectively.

In 2022, students were asked to evaluate their perceived learning outcome of each resource individually. For the digital STACK assignments, 82.3% of respondents reported a good or very good learning outcome and for the learning videos, 76.2% of respondents reported a good or very good learning outcome. The corresponding results were 76.5% for digital scaffolding exercises, 42.4% for previous exam questions, 35.5% for Jupyter Notebooks, 33.8% for the digital plenary lecture, 48.0% for the campus lecture, and 28.1% for the textbook.

5 DISCUSSION

In this paper we have presented a method of blended teaching in a statistics course for engineers. In this course we propose a learning path that students may use to navigate various digital recourses and on-campus activities. The deadlines for the mandatory element of the course (weekly quizzes) are set by us, and as seen in this paper the deadline has a clear impact on the overall pace of studies. However, by using short topic videos as the main 'lecturing' format, we have shifted the control of timing and pace of lectures from the lecturer to the student.

When we in 2021 gave the students a late deadline (one week after the topic was 'lectured'), about half of the students were delayed both when it came to starting the assignments and watching the videos. As the videos were intended to be viewed prior to the mid-week campus-lecture, the delayed students were likely either skipping all lectures or having a poor learning outcome if attending. This delay in student behaviour also led one of the campus-lecturers to change the format of the session; instead of covering examples that should expand the week's curriculum, the lecturer had to introduce the curriculum. Based on statistics from 2022, we see that a stricter deadline for the assignments coincides with the students engaging with the digital resources in line with the suggested learning paths. The proportion of students doing the assignments and using the short topic videos as a learning resource was however similar between these two years.

Although we have no official statistics, we would guess that by the end of the first nine weeks, about 30% of the students attended digital and campus-based sessions. Clearly, far more students watched videos than attended lectures and one can of course speculate whether attendance would improve if less material was covered by the videos. From survey results we also see that the students rate the videos as far more important for learning than the lectures. This is somewhat unsurprising given the attendance rates, and when keeping in mind that the videos introduce new theory which the campus sessions build upon and extends.

Our results must also be viewed in the relevant context; both due to the pandemic and the cross-campus nature of the engineering programs at NTNU, our students are used to – and expect – a digital or hybrid learning environment in basic courses. For us, the use of learning videos instead of solely campus-based lectures ensures fairness and equal opportunities across campuses. It should be noted that the efforts made by the team of lecturers to produce all learning materials in 2020 (and thereafter improving and updating) have been substantial. However, we have tried to make a course where we minimize the amount of work being done in parallel across campuses and distributed various development tasks among the team of lecturers.

In this study we have focused on students' use of digital learning resources, revealing different strategies chosen among students in two semesters with the same blended learning environment. We find that with sufficient guidance - which includes both learning paths *and* appropriate deadlines - to the navigation of learning resources, the engineering students successfully engage with digital learning resources for learning statistics. Of note, our top-rated learning resources were developed according to current advice; short learning videos (5-15 min) and exercises with immediate feedback (formative assessment) complemented by step-by-step help exercises (scaffolding). For further work, we are focusing on improving the integration of Python programming, and on the end-of-term team-based engineering projects.

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TRANSFORMING CURRICULUMS FOR AN AGE OF MULTI-MODAL EDUCATION: A 5 PHASE APPROACH

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ABSTRACT

The pandemic has accelerated the trend towards online and hybrid learning with many educational institutes pivoting their education to online learning environments and has subsequently transformed societal expectations. There have been many benefits associated with these changes (e.g., multi-dimensional interactions, flexibility and deep learning). As we move into more online education due to changing needs and demands from students, how best to adapt our education for multi-modal learning environments can be a challenge. Getting our education ready for a multi-modal age is bringing about disruptive changes forcing us to rethink what we teach and how we teach it. **Thus, the objective of this paper is to present a framework that will allow for the evaluation of curriculums and enable educators to create sustainable, flexible educational environments relevant for multi-modal learning environments while remaining at the forefront of educational needs.** In this paper, we present the 5-phase approach that we used to assess our programme and redesign our curriculum. The five phases include: Inventory, Analysis, Evaluation, Design and Implementation. We will present the highlights from our experience and the challenges we have had to overcome. The framework that we present is applicable to different computer science, spatial and data engineering programmes that require a mix of theoretical and hands-on practicals.

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1 INTRODUCTION

1.1 Background

The pandemic forced educational institutes to pivot their education to online learning environments and has subsequently transformed societal expectations. With the advancement of digital technologies, we can provide very rich and multi-dimensional learning environments. Although there have been many benefits associated with these changes (e.g., multi-dimensional interactions, flexibility and deep learning) there are still many challenges that can result in poor and often inadequate educational experiences. Since staff have had to convert their courses to make them fit for online delivery, which served an immediate purpose, there now has been time to reflect and see room for improvement.

At the same time that educational transformations are taking place, so too are transformations within our own discipline of geospatial information and earth observation sciences due to advances in technologies and the integration of machine learning and artificial intelligence methods. A key part of the skills students require are those of data, software and spatial engineers that range from the creation and fusing of data to make data useable and operational or software and technological engineering. These advancements highlight the need for us to update our curriculum so that we can incorporate new skills, methods, technologies, knowledge and competences as they relate to the geospatial field and the needs for this profession while also transforming how we teach. As we move into more online education, due to changing needs and demands from students, the question now is how best to adapt our education for multi-modal learning environments and create a high-performing digital education ecosystem that is flexible. **Thus, the objective of this paper is to present a framework that will allow for the evaluation of curriculums and enable educators to create sustainable, flexible educational environments relevant for multi-modal learning environments while remaining at the forefront of educational needs.**

1.2 Online education

In 2020, all face-to-face (f2f) education around the world closed. The ad-hoc necessity to provide online education affected all aspects of education (Blanford et al. 2021) that required transitioning learning environments in a short-period of time (Bryson and Andres 2020). Staff were required to transform, adapt and develop infrastructure, curriculum, pedagogy and skills (e.g. digitalization of education and incorporation of video, videoconferencing and other media (Smolle et al. 2021)) to make courses ready (e.g. (Bogdandy, Tamas, and Toth 2020)) instantly. Many challenges were faced that included barriers due to technology, internet connectivity and availability (Demuyakor 2020, USAID 2020, Cullinan et al. 2021), ethical concerns (see references within (Turnbull, Chugh, and Luck 2021)) related to privacy (Rajab and Soheib 2021), inclusion (Parmigiani et al. 2021) and inequality (Pittman et al. 2021). Although the transition to online education started as a response to the pandemic, finding the balance between f2f and online learning is the next step in developing resilient educational systems (e.g. (Schultz and DeMers 2020)).

Many master's degree programmes are available in a variety of formats (full-time, part-time, face-to-face, blended, online). Online is increasing in popularity with working professionals who are unable to move to the education facility full-time due to family obligations and are in a good job. Flexible study options via part-time and online provides many professionals the opportunity to continue to advance their existing competences and develop new skills and knowledge. Different modes of education can include **blended learning/flipped classroom** (combines face-to-face classroom time with online learning) or b**lock mode learning** which involves intense face-to-face study over a fixed period, often weekends or consecutive days allowing students to book time off work in advance. In this paper we focus on education in fields that merit from the benefits of online education but are also greatly dependent on hands-on learning by doing such as lab-work and field experiments, often requiring physical presence of students. For education in these fields, we need to find an optimal mix of multiple education modes.

1.3 Geospatial Engineers and Spatial Data Engineers

Geospatial engineers and Spatial Data engineers require a variety of competencies that include a range of workplace, academic and personal skills alongside a range of technical skills (see (Blanford et al. 2020) for competencies). In essence the types of skills needed by geospatial professionals include:

- Data engineering
- Data Visualisation and Exploration
- Spatial Analysis
- Modelling and scripting that may extend to software engineering with the creation of new technologies and applications.
- Machine Learning & Artificial Intelligence
- Big Data Analytics
- Open Science, Ethics & Governance

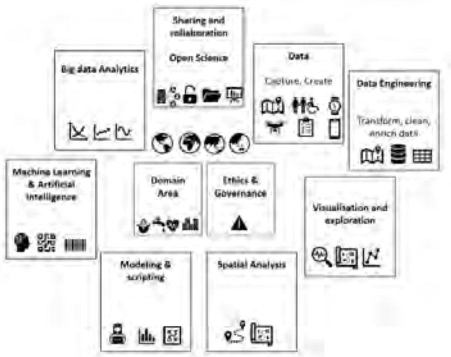

Fig 1: *Overview of the skills needed by geospatial professionals.*

With technological improvements, dealing with increasing amounts of data in different velocities, volumes and validity (V's), big data analytics and processing is of increasing importance alongside the need for using different types of information across a variety of domains such as responsible GeoAI, Disaster Resilience, Resource Security and GeoHealth. Students need to learn these skills to enhance decision making, develop solutions and for achieving the many sustainable development goals across a variety of disciplines.

The master's programme that we offer, enables graduates to address worldwide challenges in a local context using the core knowledge areas of Geo-Information Science and Earth Observation. The programme aims at providing graduates with the skills and knowledge that enable them to provide solutions that contribute to the sustainable development of societies. We have created an international multi-cultural educational environment that brings together students and staff from around the world. Through this diverse learning environment, we provide a rich learning experience that enables for the co-creation of geospatial solutions for addressing global challenges and provide solutions for sustainable development.

2 METHODOLOGY

2.1 Framework for redesigning the curriculum.

Redesigning of curriculums or educational programmes requires many aspects of the programme to be (re)considered, which all start with creating and updating measurable learning outcomes, selecting appropriate and effective teaching strategies to enhance learning experiences and aligning assessment methods with learning outcomes.

In general, redesigning of curriculums is a multi-staged process that involves (i) *analyzing* the current educational situation by gathering information, (ii) *designing* a new curriculum, (iii) *implementing* of updates and changes, and (iv) *evaluation* of the updates (Nomme and Birol 2014). We have adapted these stages to fit our needs and created a 5-phase approach (Figure 2). The information gathered during Phases 1-3 will serve as input to Phase 4, designing the curriculum. Once the design phase is completed and the courses updated, we can enter Phase 5, the implementation phase. For this study we will mainly report on Phase 1-3.

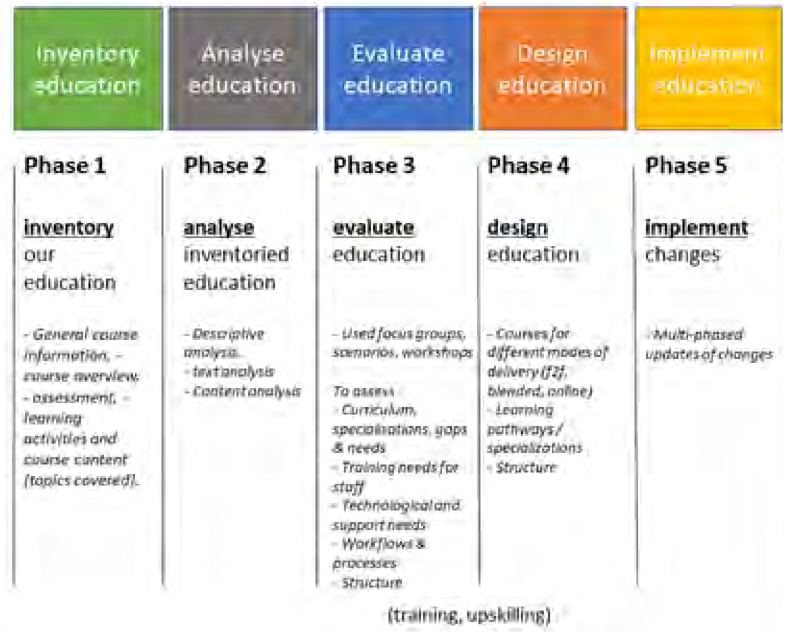

Fig 2: *Overview of the 5-phased approach for innovating the curriculum in a degree programme.*

Each of the five phases are described briefly below:

- **Phase 1: Inventory** our education captures different elements associated with teaching and learning (content, assessment, community). These include general course information, course learning outcomes, how students are assessed and what learning activities are used, what topics are covered. Pedagogical information for each course was obtained from course coordinators. Each course coordinator was provided with a form for their course pre-populated with existing information from the study guide. All coordinators checked the information and provided missing or incomplete information on learning activities, learning outcomes and information on content.

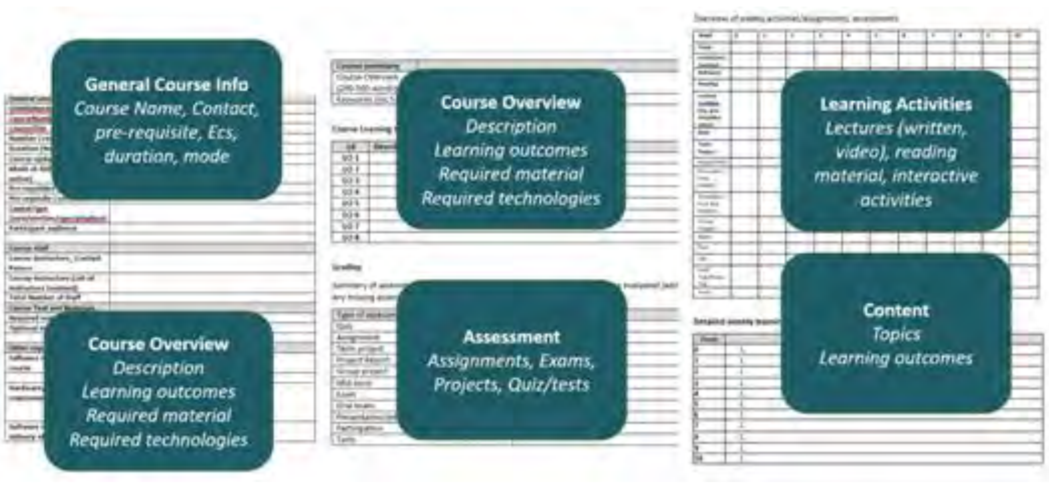

Fig 3: *Example of a form used to capture detailed course information. The elements were transferred to an excel spreadsheet and later used to populate a database.*

- **Phase 2: Analyze** the data captured in the inventory (what didactic methods were being used; what assessments were used; what topics were being taught). The inventoried information was analyzed using descriptive statistics. Voyant Tools (https://voyant-tools.org/) was used to analyze text and included creating word clouds. Thus, we examined the curriculum, relationships between courses, identified gaps or isolated topics (Fig 4) and evaluated the programme and how what we offer relates to the geospatial competencies required in this field.

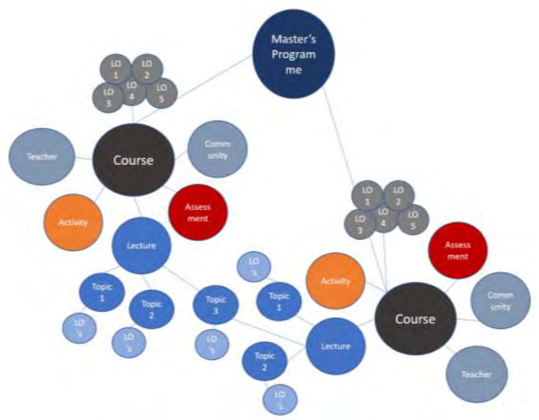

Fig 4: Conceptualisation of course components for the master's programme and how courses may be connected.

- **Phase 3**: **Evaluate** our education. We further evaluated our education using findings from Phase 1 and 2, combined with external inputs from, for instance, our professional advisory board. These served as input to discussions and activities during workshops, interactive focus groups and collaborative design sessions. Internal and external surveys were used for additional data gathering and polls to finalize decisions and clarify ambiguities during sessions. We included students and staff during workshops and discussions. The findings from Phase 1-3 will serve as input for developing training and designing the programme.

- **Phase 4**: **Design** education for multi-modal learning environments. During this phase we will conceptualize the curriculum and assemble the pieces using the information collected during Phase 1-3. To aid in designing the programme we have developed a set of small pilots that will allow us to test new approaches, workflows and processes so that we can assess the feasibility of incorporating these changes and identify challenges. The pilots include:
    - (i) *appreciation for online teaching:* develop workshops and training to promote digital education skills and enable staff to develop skills for designing courses for online delivery.
    - (ii) *assessments*: evaluate variety of testing types to achieve more efficient and effective testing.
    - (iii) *designing courses and a curriculum* that use different didactical methods with the aim of achieving the same or higher learning results.
    - (iv) *create new learning pathways/specialisations*: design a new learning pathway for online delivery.

  For the design of courses and curriculum we will incorporate design elements and use storyboarding to aid in visualizing a course and the elements that make up a course (lecture, learning activity, assessment, interaction) (Laurillard 2021) to help us visualize what we are teaching and how. We will also apply these when designing learning pathways / specialisations to gain an overview of our programme and check how they contribute to the overall programme learning outcomes. We will create scenarios to examine changes in structures and how they impact different modes of learning and course flows - how courses fit together and how sequence of courses translate between different modes (face-to-face <- – -> online).

- **Phase 5: Implementation** of new courses and curricula. Changes and updates will be phased in. In particular for a multi-year master's programme, this phase can be more challenging. One-year master's programme can be changed with little consequences for new or previous cohorts of students. Multi-year programmes need to plan for curriculum changes well in advance in order to anticipate effects on students that will start or finish up to at least three years from 'now'.

3 RESULTS

We assessed all courses in our programme (N=68). The mode in which courses were delivered are predominantly face-to-face, with some online (N=3) and hybrid (N=5). On average, courses ran for 10 weeks with some running for 5 or up to 12 weeks. A variety of software is used that ranges from open source to proprietary software (Figure 5). A summary of the findings from the inventoried courses are captured in Table 1.

Fig 5: Word cloud of software utilized during the programme.

Table 1: Summary of findings from inventory

Topic	Findings	Adjustments and improvements needed
general course information	- Most details were provided - Course names not very informative - Mode of delivery is predominantly f2f - Duration of courses predominantly 10 weeks - Course levels (introductory, advanced) are not clearly defined.	- Course names could be improved - Ability to deliver in multiple modes (face-to-face, hybrid, blended, online) needs to be addressed.
overview of courses	- Course descriptions varied in detail - Learning outcomes provided for courses - Pre-requisites not defined for all courses	- Course descriptions need to be standardized. Information needs to be more concise and informative. - Learning outcomes for courses need to be refined.
assessment: how students were evaluated	- Variety of assessments are used. - Terminology of assessments varied. - Assessments were predominantly based on assignments, group projects and tests.	- Standardization of definition and naming of assessments. - Balance type of assessments - Balance individual and group-based assessments
learning activities	- Emphasis is on contact hours - Learning activities consist predominantly of lectures and supervised practical's/tutorials	- Need to balance the use of different learning activities/types to encourage more active learning. - storyboard courses and view breakdown of types of learning activities used (acquisition, discussion, investigation, collaboration, practice, production and assessment) (Laurillard 2002, Laurillard 2021) to enhance learning activities.
details about the content	Mixed level of details	Additional details are needed, and a minimum set of standards need to be defined
	Geospatial Software (open vs propriety) *Good – use a variety of software, providing software resiliency*	*None*
	Duplication of content - *Identified several courses offering similar content.* ***Fragmentation -*** *Fragmentation of topics and lack of clarity of depth of topics or skills* ***Gaps -*** We identified some gaps in the curriculum	*Need to consolidate similar content.* *Need to clarify depth of topics and evaluate.* *Need to develop new courses to add to the curriculum to cover knowledge gaps.*
	Core courses - *Cover a large range of topics some of which are complex topics/skills.* *Newer technologies, data sources and methodologies not visible or not covered*	*Need to re-organise and design.* *New information sources, technologies and methodologies need to be made more visible. Scripting and programming are essential and needs to become part of the core.*
	Internationalisation *Some topics and case study's capture Internationalisation. Not explicitly captured.*	*Additional exploration will be needed to make this visible in the content. Explore how to evaluate or monitor.*

In our analysis and evaluation, we predominantly examined the relationships between courses and identified gaps or redundant topics and evaluated these in combination with the input we gathered from our professional advisory board and our internship hosts. During workshops and interactive sessions, we identified challenges associated with changes in the curriculum and barriers to developing and delivering multi-modal learning environments.

4 SUMMARY AND ACKNOWLEDGMENTS

The most reassuring logical outcome of our evaluation was that the input from our current students and alumni matched very well with that from the organizations interested to hire our graduates. There is a consensus that the programme should invest more in, for instance, learning at least one programming language and should also offer space for professional development skills, such as communication skills and project management. This analysis and evaluation provided us with the necessary input to move into the design and implementation phases and enable us to make choices on which should become, for instance, mandatory subjects in the curriculum.

Challenges - We are in a perfect storm of change where technological advancements are changing how we work, teach and learn. Change is never easy and based on the psychology of change involves five stages (Gatersleben and Appleton 2007, Prochaska, Diclemente, and Norcross 1992): **Pre-contemplation**: lack of awareness of the problem; **Contemplation**: awareness of a problem, but ambivalent about making any changes. Pros and cons of change are perceived as approximately equal resulting in no commitment to change; ***Preparation****: preparing to* commit to make changes. Intent on taking actions to make changes or already starting to make small changes; **Action**: making the change. Accepting the changes needed and taking action for making changes; **Maintenance**: sustaining change. Our goals are to reach a state of maintenance where we can sustain regular ongoing changes to our curriculum. The 5-phase approach we presented here are not only useful for evaluating a course and an academic programme but also provides for management and staff to work through the different phases of change and provide time for reflection as one moves through each of the five stages of change. This also provides programme management opportunities to reflect, monitor progress and identify challenges so that they can aid in preparing for change and develop solutions to support the necessary changes needed.

C*reating an appropriate learning environment, regardless of delivery method (face-to-face, online or blended), requires a significant amount of preparation, planning and design (Palmentieri 2022).* To achieve this requires upskilling of staff and changing how we work. In cooperation with the instructional designers and e-learning staff we have developed workshops and training sessions to enable for staff to improve their didactical skills so that they can adapt their courses for multi-mode learning. This will be an ongoing process that will require continual adjustments to be made. Storyboarding of courses is useful for visualizing courses and can be used for providing suggestions for improvements, focusing discussions and providing suggestions for how to change or create more active learning.
Next steps - We are entering phase 4 – the design phase of our curriculum and programme. We anticipate this will be an ongoing process in the upcoming year. Similar to Phase 3, we are facilitating discussions between staff so that we can consolidate courses, re-organise courses and initiate new course developments to fill knowledge and competency gaps. In addition, we will conduct several pilots that will help us refine our curriculum (see methodology phase 4 for details). Once we have completed phase 4, updates can be implemented (phase 5).

With the recent technological advancements, we now have the ability to provide very rich and multi-dimensional learning environments. To do so requires engineering educational learning environments that will enable us to do so. The inventory of our courses and design of our inventory provides the basis for this. All of our course information is now available in a structured format that makes it easy to search for courses and topics; visualise and analyse content; evaluate content, trends and relationships; evaluate learning activities; and create personal and flexible learning pathways that can link to professional competencies (e.g. (UCGIS)). In summary we can assess what we are teaching and how we are teaching it so that we can make continual and gradual improvements.

5 SUMMARY AND ACKNOWLEDGEMENTS

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A THEORY-BASED TEACHING CONCEPT TO EMBED SUSTAINABILITY IN THE ENGINEERING CURRICULUM

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ABSTRACT

The implementation of sustainable development and the responsible use of the resources available to us are among the key objectives of our time. To meet the challenges of global sustainable development, young professionals with a growing set of skills are needed. Higher education is crucial in fostering the skills graduates need to become agents of change for sustainable development. Therefore, new teaching and learning approaches are needed in engineering education that link technical and sustainability-oriented topics and integrate education for sustainable development (ESD). Studies show that there is a particular lack in the design and implementation of engineering courses that address the close connection between technical and sustainability-oriented issues and contribute to the promotion of the new required competencies. This paper addresses this gap, in which the authors present a teaching example for sustainable engineering education. The article presents the implementation process of a research-based concept. The aim of the module is to expand and strengthen students' competences in the field of sustainability. Various didactic teaching and learning methods were used. Thus, an attempt was made to

combine learning aspects from education, sustainability and engineering and thus to ensure more sustainability in engineering education. The article provides an overview of the structure and the most important components of the module. The knowledge gained will contribute to the evidence-based implementation of sustainability in the engineering sciences. The presented findings should serve as a basis for discussion for the community and contribute to the further development of teaching concepts for sustainable-technical education.

1 INTRODUCTION

The implementation of sustainable development and the responsible use of the resources available to us are among the key objectives of our time. Higher education is crucial in fostering the skills graduates need to become agents of change for sustainable development [1]. Therefore, new teaching and learning approaches are needed in engineering education that link technical and sustainability-oriented topics and integrate ESD [2]. Studies [2-6] show that there is a particular lack in the design and implementation of engineering courses that address the close connection between technical and sustainability-oriented issues and contribute to the promotion of the new required competences.

This is where this paper starts by working with two research questions:

> ***(1)*** How are sustainability issues currently represented in engineering education research (EER)?
>
> ***(2)*** How can a theory-based concept for the integration of sustainability issues in engineering look like and how can it be implemented?

In the sense of design-based work, the pursuit of these two research questions provides both a contribution to the research landscape of engineering sciences and a contribution to teaching practice. The necessary methodological procedure is described in sec. 2. In order to implement sustainability in study program across the board, concepts must be developed. The level of engineering education research (EER) is relevant for this. Methods and theory-based concepts must be developed to integrate sustainability into the engineering degree program, and these in turn must be integrated into teaching practice. Due to the increasing urgency of the problem, concept development and implementation must proceed in parallel, cf. [7,8].

For research question ***(1)***, an introduction and overview of the integration of sustainability in engineering is given. In section 3, a literature analyse shows to what extent the topic of sustainability is currently addressed in the research landscape of EER and which specific concepts exist that integrate sustainability aspects in engineering education. In this context, an analysis looks at the research landscape in EER to find out to what extent sustainability has been addressed between the years 2014-2018 and 2021. For this purpose, the mention of sustainability in 3,570 conference articles was evaluated. As a result of that survey, it becomes clear that there is a research gap especially in the development of theory-based teaching concepts for linking sustainability and engineering.

To answer question ***(2)***, this research gap will be addressed. In section 4, an exemplary teaching-learning concept is developed and transferred into practice. The aim is to develop an interdisciplinary concept that enables the integration of sustainability topics into the engineering sciences in order to promote sustainable development. The elective module was carried out in the Master's degree program " Management & Engineering" in the winter semester 2022/2023 at Leuphana University. Section 4 describes the learning objectives as well as the developed concept, first student feedback is evaluated. The concept is intended to serve as a guideline that enables other engineering program or universities to implement a similar module and simplifies the integration of sustainability topics into the engineering sciences.

2 METHODOLOGY

“Methodology can be seen as the strategy, the plan of action, process or design lying behind the choice and use of particular methods and linking a choice and the use of methods to the desired outcomes” [9]. For a successful completion of the research question it is necessary to clarify the connection between the research goals and the selected methodology. The research objectives in this article are standing for both, theoretical understanding and educational practice. In order to design and to study within the same research process (see [10]) we´ve chosen design based research. Design based research is a multi-faceted approach that "...can yield valuable results for both theoretical understanding and educational practice" [10]. The generic model for educational design research is shown in fig.1. This methodology has also been used because the main stages of the research interact with the educational practice. In this way we were able to achieve our research objective by dual outputs of innovative approaches and theoretical findings. Fig.1 presents the three stages of the process model for the design based research: Analysis, Design and Evaluation. All three stages are implemented in the research process and are explained below.

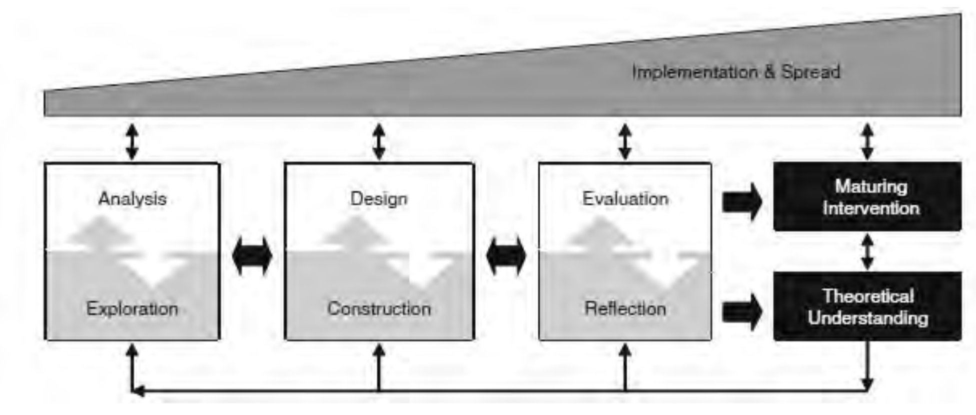

Fig.1. Generic model for conducting educational design research [11]

Within the ***analysis phase*** we surveyed the EER landscape. The result is a research-guided category system consisting of ten main categories and 78 subcategories that encompasses the essential aspects of the research field, their specification, and the relationships and delimitations of the individual categories to one another (exemplified by the example of sustainability in Section 3). General statements of the overall analysis are given in [3], the results with a focus on linking sustainability and engineering are presented in section 3. For the purpose of gaining knowledge at the interface of engineering and sustainability, two leading IEEE conferences of the international EER research landscape, the FIE and EDUCON, were selected as the basis for the systematisation, whose publications appear annually in a two-stage blind review process. With the aim of an international and up-to-date analysis, contributions to EDUCON and FIE from the years 2014 to 2018 and 2021 (EDUCON only) were systematically analysed and categorised using a catalogue of categories developed in advance. In doing so, EDUCON, like SEFI Annual conferences, focuses more on the European research landscape, while FIE expands the research work to include a more international (especially american) view. This approach addresses the critiques of [12-14], who point to existing disciplinary and geographical divisions in the research landscape. Although the research presented does not provide a complete overview, basic statements and research trends on sustainable engineering education can be derived. The number of articles from the respective years that were used to categorise the scientific articles is presented in Tab. 1.

Table 1. Number of published and categorised papers of the international EER conferences Global Engineering Education Conference (EDUCON) and Frontiers in Education Conference (FIE) in the years 2014 - 2021, own data.

Year	EDUCON	FIE	Total
2014	196	519	715
2015	154	403	557
2016	191	410	601
2017	289	306	595
2018	300	537	837
2021	265	-	265
Total number of categorised paper			**3,570**

Based on the findings we next turned our attention to the development and the implementation of a theory-based concept to embed sustainability in the engineering curriculum, worked out in section 4.1 and 4.2. This ***design stage*** of the design-based research process was followed by evaluation process. To register statements about students understanding and feedback to the module an ***evaluation*** was undertaken, that results of which are presented in section 4.3..

3 ANALYSIS OF THE EER-LANDSCAPE REGARDING SUSTAINABILITY

The total of 3,570 FIE and EDUCON conference articles from 2014-18 and 2021 (EDUCON only) were each assigned a minimum of one and a maximum of two main and sub-categories. A total of 6,627 categories were assigned. What is noticeable in the overview of the results of the category allocation is the lower number of allocations in the contributions to EDUCON, which can be attributed to the different absolute number of contributions to the respective conference (see Tab. 1). In both conferences, topics in the context of teaching and learning processes were addressed most frequently by far. For limited reasons, a more comprehensive overall evaluation is not included in this paper, as the focus is on the evaluation of the topic area of sustainability. The category "Topics related to Engineering" as one of the 10 main categories categorises publications that place the thematic focus on topics that are not subject-specific but are related to engineering content [3]. One of the subcategories belonging to this main category is “Sustainability”. In the following, the number of contributions dealing with the topic of sustainability is quantitatively highlighted. The results are analysed qualitatively.

Fig.2 gives an overview of the categorisations of the articles of the FIE and EDUCON to the sub-category sustainability over the years. Out of a total of 6,627 categorisations, 48 (0.72%) were made in the sub-category "Sustainability". By way of explanation, it should be added that a category is only awarded if the *majority of the contribution* deals with the theme. Most articles were sighted in 2017. In general, the proportion of articles that address the topic of sustainability is extremely low at 0.72%, which illustrates and supports the situation described in the introduction. Contrary to expectations, there is no trend to be noted in the results.

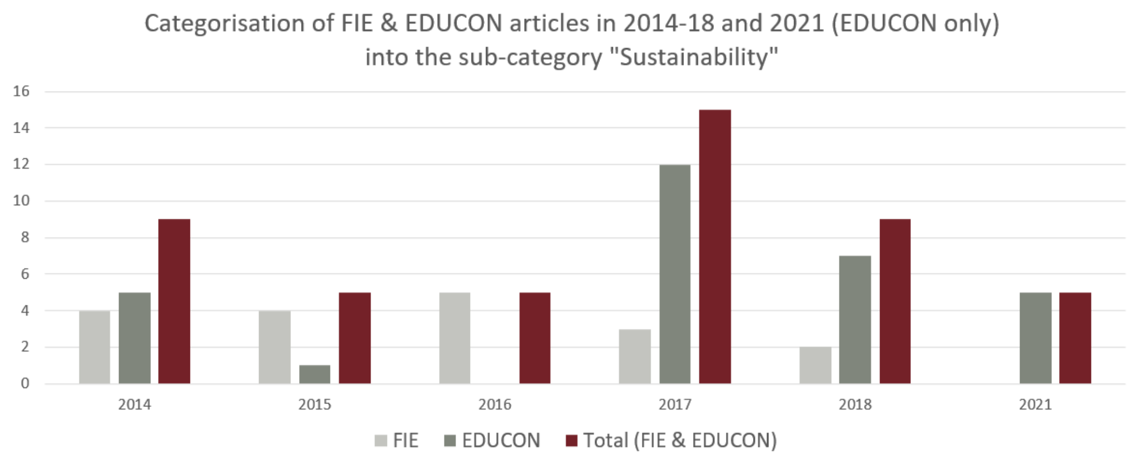

Fig.2. Categorisation of FIE & EDUCON conference articles in 2014-18 and 2021 (EDUCON only) into the sub-category “Sustainability”, own data

In order to find out whether the topic of sustainability nevertheless plays a role in the categorised articles, a "COUNT IF" query was carried out in Excel. It was analysed how often the word "sustainability" was written in the title (9 times), in the keywords (20 times) and in the abstract (39 times). In addition, the words "sustainable" and "climate change" were filtered. The word "sustainable" appeared in a total of 18 out of 3,570 titles, in 17 keywords and 55 abstracts. "Climate Change", on the other hand, was only mentioned once in the title and keywords and three times in the abstract. The occurrence of the word "sustainable" should be interpreted with caution, as it refers not only to sustainability aspects, but also, for example, to long-lasting projects that do not directly include sustainability issues. With a total of only five mentions, the occurrence of the word "climate change" can be neglected. Fig.3 shows the frequency of the word "sustainability" in the title, abstract and keywords depending on the year.

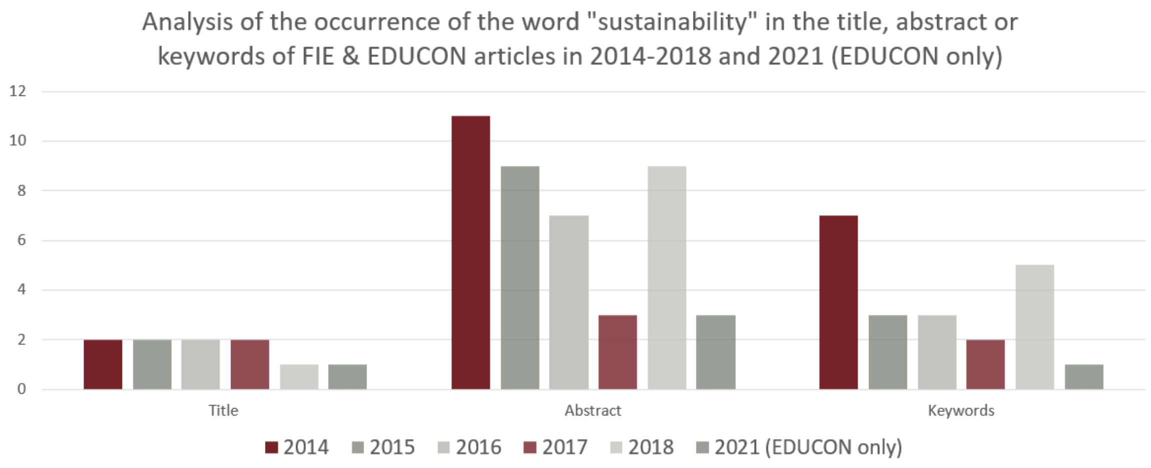

Fig.3. Analysis of the occurrence of the word "sustainability" in the title, abstract or keywords on FIE & EDUCON conference articles in 2014-18 and 2021 (EDUCON only), own data

The latter analysis confirms the results of the categorisation, as the frequency of the keywords is in similar dimensions to the allocation of the articles. Basically, however, it becomes apparent that very little relevance is attributed to the topic of sustainability in engineering education research and practice, which urgently needs to be changed. An approach for integrating sustainability aspects in engineering education is therefore presented in the following chapter.

4 THEORY-BASED THEACHING CONCEPT FOR SUSTAINABLE ENGINEERING EDUCATION

In order to anchor sustainability aspects in the teaching of engineering and to strengthen the students' awareness, especially in the area of social and ecological sustainability, a teaching-learning concept was developed based on the theoretical findings of the analysis and constructivist learning approaches, e.g. [15].

4.1 Teaching concept for sustainable competences in engineering

The developed concept for sustainable competences in engineering is shown in Fig. 4. It consists of a triad of a content level, a methodological-didactic concept and an individual process level. With the concept, a structured program development is designed that promotes the teaching of sustainability aspects in an engineering context, can be flexibly adapted to the interest of the students and involves the participants in the design of the module through the flipped classroom approach. On the ***content level***, the technical basics in the areas of sustainability science and didactics are first taught. The Blue Engineering Concept [16] is included in this. By participating in the first thematic teaching-learning modules, students should begin to understand the interactions. Through the selection and implementation of an existing

Blue Engineering module as well as the subsequent deepening of the content of a self-selected topic, the participants should acquire professional basics.

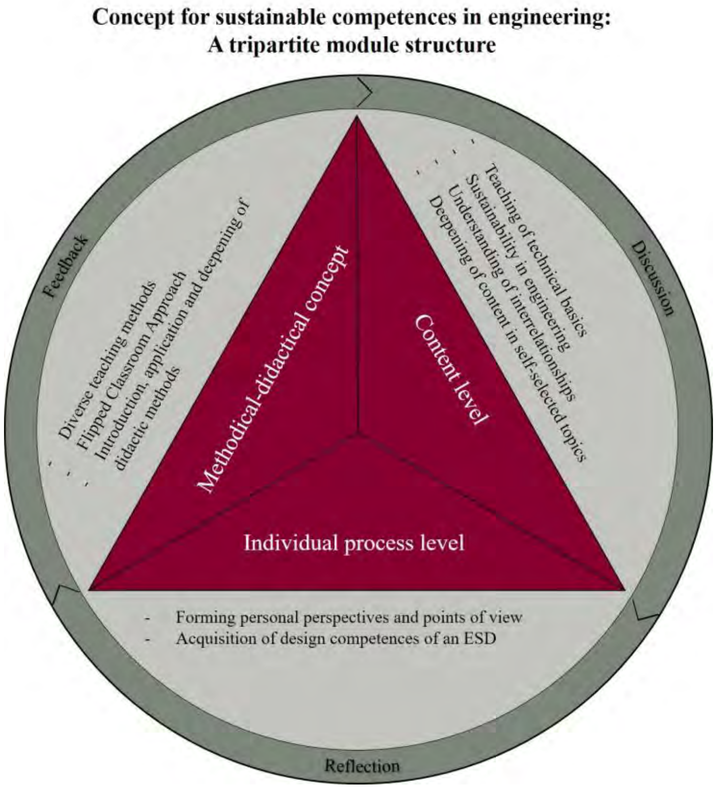

Fig.4. Teaching concept for sustainable competences in engineering

For a successful ***methodological-didactic concept***, a variety of learning methods are to be used. Personal perspectives and points of view should be developed and enable participants to act. The acquisition of factual and methodological competence, social competence and self-competence on an ***individual level*** should take place.

4.2 Implementation

The 5 CP module "Sustainable (Blue) Engineering" was designed for 15 participants and offered in winter semester 2022/2023. The learning group consists of students of the Master's program "Management & Engineering" at Leuphana University. The biweekly 3.5-hour course was structured as follows, so that a step-by-step approach and deepening of the interplay between technology and sustainability was possible:

- **Teaching the basics in the subject area of sustainability in the engineering sciences (**Introduction to didactic methods and feedback rules, Introduction to Sustainability Science, Participation in initial teaching-learning modules)
- **Application of the basics in the subject area of sustainability in the engineering sciences (**Application of didactic methods and feedback rules, Teaching content on the topic of engineering and sustainability, Preparation and implementation of existing Blue Engineering teaching-learning modules)

- **Exemplary deepening through the development of own teaching-learning modules (**Choice of didactic methods for teaching the chosen topic, Examination of the content of self-selected topics, Implementation of the self-developed teaching-learning modules)

4.3 First findings and feedback

At this point, the first findings of the evaluation are presented, in particular the participants' feedback on the course. It should be noted that the evaluation is not to be understood in the sense of a complex effectiveness analysis, but rather aims to provide insights into initial implementation experiences and student feedback on the implementation of the program. A selection of the student feedback is shown in Fig. 5. The results show that the students are very satisfied with the course and their knowledge gain and that the module motivates them to engage with and reflect on the topic. In general, these statements can be considered as implementation success. Further findings can be presented at the SEFI 2023 conference.

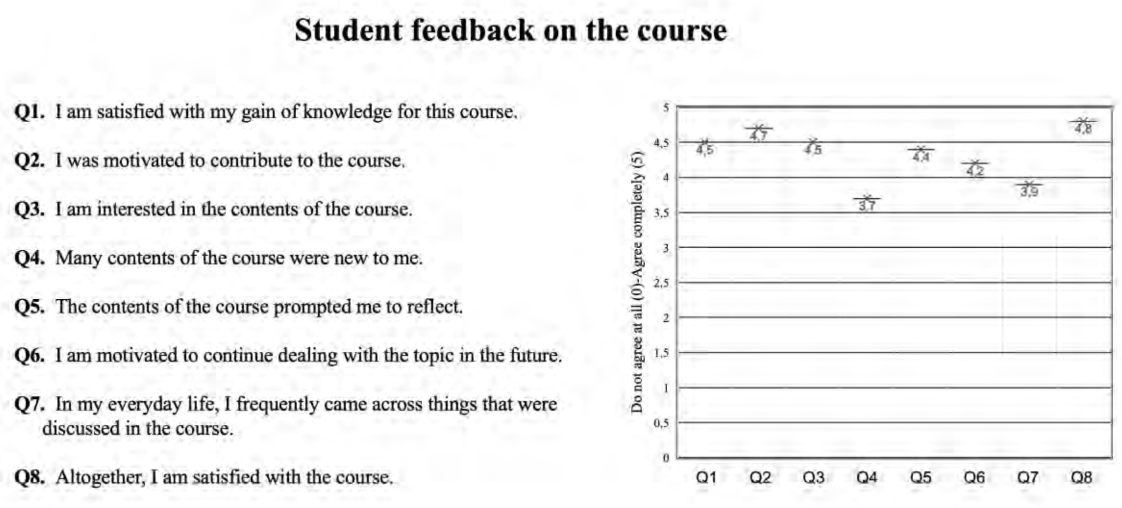

Fig.5. Student Feedback on the Course (own data)

5 SUMMARY

The paper provides research-based evidence that the topic of sustainability has so far been underrepresented in engineering, which is why evidence-based interdisciplinary implementation procedures, as presented in Section 4, are highly relevant. An interdisciplinary approach has been developed and implemented in educational practice. The course received positive feedback from participants and allowed for knowledge growth. Further module runs are planned in the coming semesters in order to continuously evaluate, adapt and optimize the developed concept.

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CONCEPTUAL MODELLING AS AN OVERARCHING RESEARCH SKILL

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ABSTRACT

Today's society is impacted by complex, fast and continuously changing problems. These need to be tackled inter-, multi and transdisciplinary. At the University of Twente, we have developed a new CBL minor *Intelligence, creativity, and responsible technological innovation in societal transformations*, (ICR&TIST), which focuses on research skills in complex socio-technological problem-solving contexts. The design of this minor has been guided by new insights from long-running research aimed at developing a *Philosophy of Science for the Engineering Sciences* and extensive experiences with engineering education in project-based learning (PjBL).

Education in scientific research tends to focus on academic contexts, while scientific research in real-world problem-contexts (e.g., sustainability) requires the ability to effectively and responsibly construct relevant, reliable and intelligible knowledge for the benefit of the concrete, local problem and possible solutions, using everything science has to offer (knowledge, methods, instruments, mathematical tools). This type of scientific research calls for a *new paradigm*, called an *engineering paradigm of science*. *Conceptual modelling* (rather than hypothesis testing) fits better the core activity of this type of scientific research and should therefore be seen as an overarching skill.

The educational design of the minor has adopted conceptual modelling as the overarching learning objective. This new concept, how to work with the accompanying conceptual modelling methodology (B&K method) and understand the underlying philosophical insights appears exciting and challenging for the multi-disciplinary educational-design team. This paper will elaborate on the educational design process, the resulting design of the minor, and preliminary findings in the pilot-phase.

1 INTRODUCTION

1.1 Conceptual modelling as research skill in socio-technological problems

Today's society faces complex and rapidly evolving problems that require interdisciplinary approaches. At the University of Twente, we have developed the *Intelligence, creativity, and responsible technological innovation in societal transformations* (ICR&TIST) minor, which focuses on research skills in socio-technological problem-solving contexts. This paper introduces conceptual modelling (CM) as a research skill suited for complex real-world problem-contexts, such as sustainability. By effectively and responsibly constructing relevant and reliable knowledge, CM enables the utilization of scientific resources. The changing paradigm of science, specifically the engineering paradigm, is discussed in relation to CM, along with the B&K method for constructing and analyzing conceptual models. The implementation of CM as an overarching research skill in engineering education is highlighted, along with the identified barriers that require further investigation.

1.2 Research in the engineering science: experiences and insights

The author's background in chemical engineering and *process optimization research in industrial bioleaching processes* (e.g., Boon 1996a, Boon and Heijnen1998) aimed at developing *sustainable technologies* has acted as a moral and epistemological concern that motivated philosophical inquiry. For example, a contribution to a book about sustainable futures raises questions about the role of (academic) scientific research:

> “In discussions about the relation between science and sustainability at least four questions come to the fore. (1) What should be the role of science in a society aiming at sustainability? (2) Is science as practised today appropriate for a sustainable society? (3) Do we have indications that point at the emergence of new methodologies and paradigms relevant for the realization of sustainability? (4) Can we come up with proposals for eliminating or creating (un)favourable conditions for the role of a new science in a sustainable society?” (Boon and Doorman 1994).

The *normative epistemological* focus in developing a *philosophy of science for the engineering sciences* (Boon since 2001) therefore primarily concerns the *quality of scientific research and education practices* in view of their societal contributions (e.g., to sustainability), where *ethics in technology* acts in the background.

Philosophical reflection during the research project, shed light on several challenges regarding the role of science, including the difficulty in integrating fundamental scientific knowledge and misaligned expectations between technologists and microbiologists. Furthermore, the lack of deeper scientific understanding in industrial research and the translation of concepts without considering scientific understanding are highlighted. The tension between publishing academic articles conforming to reductionist research methodologies and generating practical scientific understanding for industry is also discussed. These experiences contribute to the identification of a gap between fundamental and applied research, leading to the realization that expectations of scientific research do not always align with practical and societal needs.

1.3 Overview

The paper briefly explains the importance of philosophy of science for the engineering sciences in bridging the gap between fundamental and applied research. By critically reflecting on the value and relevance of scientific research for reliable, relevant and responsible knowledge production in socio-technological contexts, philosophy helps reshape research approaches and education therein.

The paper then moves on to discuss aspects of the *philosophy of science for the engineering sciences* that underpins the proposed interpretation of conceptual modelling. This includes replacing the *traditional physics paradigm* by an *engineering paradigm of science*, better suited for understanding the role of scientific research in addressing complex socio-technological problems.

The engineering paradigm of science emphasizes, among other things, the production of *relevant, reliable and useful knowledge* as a goal of scientific research. Regarding the *quality of scientific research practices*, this implies for example that, in contrast to emphasis on universal knowledge and reductionism in the physics paradigm, the focus should be on the construction of relevant and reliable knowledge (including technological and mathematical tools) for specific problems. This normative basis raises the epistemological question of what this implies for scientific research and teaching practices. The engineering paradigm emphasizes that conventional reductionist approaches are not necessarily the best, and relatedly, that applying fundamental scientific knowledge is less straightforward than the physics paradigm suggests. In addition, *interdisciplinary research* is crucial for knowledge production for real-world contexts, which is notoriously difficult and not straightforward either. Conceptual modeling aligns with this paradigm and provides a framework for effectively addressing complex problems in scientific research projects.

To further develop the quality of academic engineering education, the paper suggests conceptual modelling as an overarching learning objective that contributes to the ability of engineers in professional roles to conduct scientific research in complex socio-technological context. The B&K method, which aids in the construction and analysis of conceptual models, is explained in detail. Finally, the paper briefly discusses the educational design of the (30 ECTS) ICR&TIST minor.

2 PHILOSOPHY OF SCIENCE FOR THE ENGINEERING SCIENCES

The philosophy of science examines beliefs and views about science and their impact on research practices. Commonly, ideas about science are influenced by physics as an example of "real" science. However, it is essential to determine if these ideas are suitable for the engineering sciences or if they hinder problem analysis and solutions. Based on my experiences in the engineering sciences, I hypothesized that our current ideas about science justify research practices but may not always be productive as desired (Boon 1996a, 1996b, 2006, 2011a). Therefore, an alternative understanding of science is necessary, specifically a paradigm of science that better suits the engineering sciences (Boon 2017). Developing a philosophy of science for the engineering sciences has been a focus of my research for the past twenty years.

In typical discussions about science, the emphasis is primarily on evidence for scientific claims, which is evident in scientific articles and how they are read and taught. The content and methodologies of science education revolve around conveying proven scientific knowledge and evidence-oriented research methodologies like hypothesis testing. Students are often taught to critically assess whether the methodology and collected data sufficiently support the conclusion. The philosophy of science uses the term "context of justification" to describe this focus on evidence. The “context of discovery,” on the other hand, encompasses aspects like creative thinking, formation of concepts, understanding and conceptualization, and various reasoning processes that cannot be considered as evidence.

These discussions reveal several important assumptions about scientific research. Firstly, the normative claim that evidence for scientific claims should solely consist of objective data and logically valid arguments. Secondly, the metaphysical belief that such evidence provides certainty or proof of the (approximate) truth of scientific claims. Thirdly, the belief that the goal of science is to produce true claims about physical reality. Lastly, the epistemological belief that true knowledge about specific instances can be deduced from proven scientific claims. These assumptions are part of a paradigm of science called the *physics paradigm*.

However, contemporary philosophy of science and historical case analysis have shown that these assumptions are philosophically problematic and inadequate in representing successful scientific practices (e.g., Knuuttila and Boon 2011). The dominant physics paradigm often overlooks crucial aspects of scientific research, particularly in applied sciences like the engineering sciences. As a result, an alternative paradigm of science, termed the *engineering paradigm*, is necessary. The engineering paradigm emphasizes that the construction of knowledge is an inseparable part of understanding and justifying scientific knowledge claims (Boon and Knuuttila 2009). It challenges the unjust distinction between the context of discovery and the context of justification and proposes the "context of construction" as an alternative (Boon 2022).

Thomas Kuhn (1962) introduced the concept of paradigms and paradigm shifts in science. A paradigm encompasses symbolic generalizations, metaphysical presuppositions, values to judge theories, and exemplars (Kuhn 1970). Inspired by Kuhn's work, contrasting paradigms of science have been developed: the physics paradigm and the engineering paradigm (Boon 2017). These paradigms allow for the examination of differing beliefs about science. For example, the engineering paradigm focuses on constructing useful knowledge for specific applications, while the physics paradigm assumes the discovery of pre-existing entities and phenomena.

The engineering paradigm has implications for ideas about scientific knowledge, methodology, and education. It recognizes the roles of technological instruments and human understanding in generating and interpreting data. Scientific knowledge is seen as representations of human understanding, constructed using empirical knowledge, measurement tools, scientific concepts, theories, and mathematics. The engineering paradigm acknowledges the contributions of conceptual and instrumental resources in scientific knowledge construction, which the physics paradigm tends to ignore.

The alternative engineering paradigm of science has profound implications for conceptual modeling and provides a richer understanding of its meaning.

3 CONCEPTUAL MODELLING

The term 'conceptual modelling' is not new. Robinson (2008), for example, stresses the importance of conceptual modelling for (computer) simulation, while Thalheim (2010, 2012) declares that conceptual modelling is one of the central activities in computer science. It involves creating schematic descriptions of systems, theories, or phenomena using concepts to enhance the model. However, these authors also consider conceptual modelling the most difficult and least understood aspect of e.g. computer simulation studies.

There are three types of scientific models: those deduced from abstract theories, visually represented models of unobservable entities, and heuristic models used as aids. The first type aligns with the physics paradigm, where the model is derived logically or mathematically from the theory. The second type represents invisible entities or phenomena and relies on the similarity between the model and the real-world entity. The third type, heuristic models, are not intended to be realistic but serve as tools.

In an engineering paradigm, models are not literal representations but rather how researchers imagine and conceptualize the (invisible) phenomenon. These models contain essential information expressed verbally and visually, making them *thinking tools* (called *epistemic tools*) within a specific context. Models (esp. conceptual models) are thus considered *epistemic tools* that help researchers think about and interact with the phenomenon they represent, as well as the ever further development of these models (Boon and Knuuttila 2009).

To illustrate this view on models, the example of Sadi Carnot's conceptual modelling of the ideal heat engine is presented (Knuuttila and Boon 2011). Carnot's model was constructed based on already existing steam engines, aiming to understand the limits of power generation from heat (Carnot 1824). His approach involved abstracting from the technology and formulating the problem more fundamentally. Carnot's model included both abstract and practical concepts, as well as fundamental principles and existing scientific knowledge (e.g., gas-laws).

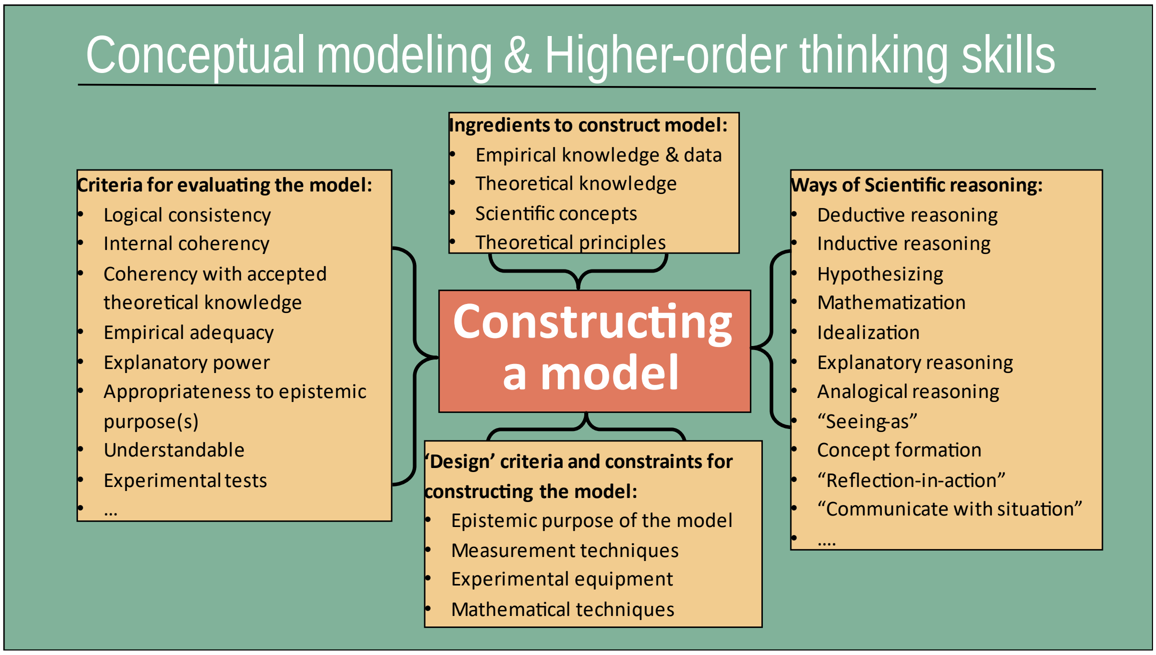

Figure 1 (Lecture slide, copy right Mieke Boon): Conceptual modelling according to an engineering paradigm of science. 'Reflection-in-action' and 'Communicate with the situation' in the scientific reasoning box (right side) refers to Schön (1983).

The B&K method, consisting of ten questions, can be used to systematically determine the aspects built into a scientific model. It helps construct or reconstruct existing models by considering relevant elements (partly listed in Fig. 1, upper and lower box). However, the B&K method is not an algorithm but a tool that requires scientific reasoning skills (Fig 1, right box) and epistemic responsibility (Boon 2020a) guided by criteria (Fig 1, left box) relevant to the intended epistemic purpose of the model.

The engineering paradigm recognizes that an algorithmic methodology for producing true or correct knowledge is not feasible. Researchers bear the responsibility of deciding which ingredients to include in the model, considering the available resources, existing knowledge, and the model's epistemic purpose (Boon and Van

Baalen 2019). This approach does not compromise objectivity and rationality but involves meeting logical, epistemic, and utility criteria (Fig. 1, box left).

“Bringing the human back into science” is an essential aspect of the engineering paradigm (Boon 2020c). It acknowledges the role of human scientific reasoning, which extends beyond logical reasoning (Fig. 1, box right). Researchers must develop higher-order thinking skills (HOTS) and engage in critical assessment of models, including the criteria used (Fig. 1, box left) and how well the models meet them.

In summary, conceptual modelling plays a central role in scientific knowledge construction. It requires intellectual skills and training in higher-order thinking for researchers. The engineering paradigm embraces the complexity of conceptual modelling and emphasizes the responsibility of researchers in constructing and evaluating models.

4 TEACHING AND LEARNING CONCEPTUAL MODELLING

4.1 Conceptual modelling interpreted from the engineering paradigm

The traditional physics paradigm of science, which emphasizes objectivity, rationality, and the pursuit of true knowledge, has influenced engineering education in unproductive ways. It limits the recognition of the human role in scientific research and overlooks the diverse ways of reasoning that contribute to scientific understanding. Academic engineering education has also adopted some of these ideas, such as the distinction between research and design and the limited roles attributed to teachers in supporting the development of HOTS by students in scientific research (Boon 2022). However, the engineering paradigm offers a different perspective, emphasizing the importance of the human ability of conducting scientific research in complex problem-solving contexts, which involves the human ability to reason in different kinds of ways (Fig 1, box right) and judge the quality (Fig 1, box left) of conceptual models thus produced.

Conceptual modelling, as interpreted from the engineering paradigm, provides a suitable approach for teaching and learning scientific research in academic engineering education. It involves understanding conceptual models as representations of researchers' understanding of a phenomenon, incorporating various contributions from technology, mathematics, and cognition, and being constructed with specific epistemic purposes in mind. Conceptual modelling serves as an overarching learning objective that involves developing other intellectual skills (Boon et al. 2022). According to the engineering paradigm, these include (non-exhaustive): problem-analysis, systems-thinking, knowledge-application, integration of heterogeneous elements, explanation, evaluation, representation, conceptualization, and logical reasoning.

4.2 Implementing conceptual modelling in academic engineering education

There are several ways to implement conceptual modelling in engineering education:

1. *Explaining abstract theory*: By reconstructing the development of a theory, such as thermodynamics or electro-chemistry, students can gain a deep understanding of its structure and content (e.g., Knuuttila and Boon 2011). The B&K method provides guidance for analyzing and identifying key components. This understanding enables students to apply the theory effectively in practical applications (Orozco et al. 2022, 2023).

2. *Analyzing scientific articles*: The B&K method can be used to analyze scientific articles, allowing students to gain insight into the content and identify important aspects of the reported research (Boon 2020a). This approach helps students overcome the challenges of reading scientific literature and encourages them to focus on the research process rather than just the conclusions.

3. *Using conceptual modelling in PjBL and CBL projects*: Conceptual modelling can be implemented as an overarching approach in problem-based and challenge-based learning (PjBL and CBL) projects (Boon 2020a). By constructing conceptual models of complex problems, students can develop a deeper understanding of the problem and the criteria for potential solutions. The B&K method provides support for students' modelling activities in these projects.

Implementing conceptual modelling in engineering education has shown positive outcomes. Teachers have observed improvements in the quality of student projects, and students have expressed an understanding of how conceptual modelling supports their research. However, students often struggle with thinking like researchers and formulating research questions. Further scaffolding is needed to develop their higher-order thinking skills, particularly in question-asking as part of the conceptual modelling proces (Orozco 2023).

In summary, teaching and learning conceptual modelling in academic engineering education aligns with the engineering paradigm of science. By implementing conceptual modelling in various educational contexts, students can develop a deeper understanding of scientific research and enhance their ability to responsibly produce relevant and reliable knowledge (including instruments and tools) for complex socio-technological problems.

4.3 Educational design of the ICR&TIST minor

The overarching learning objective of the ICR&TIST minor is to conduct trans- and interdisciplinary research. The educational design adopts a challenge-based-research-learning (CBR/L) approach in which students learn to conduct trans- and interdisciplinary research on a complex real-world problem. To this end, we have entered into a partnership with external stakeholders in the *energy-transition challenge*. Crucially, this minor is entirely skills-oriented (rather than content- oriented as in most programs focused on interdisciplinarity, see Kuiphuis-Aagten et al. 2019).

The development of so-called higher-order-thinking skills (HOTS) relevant to trans- and interdisciplinary research is promoted by eight inter-related micro-modules (1 ECTS each). The minor and micro-modules have been developed by a multi-disciplinary cross-faculty team of dedicated teachers and educational designers. The micro-modules cover conceptual modelling through the B&K method, and seven other micro-modules aimed at understanding methods and measuments in both the engineering and the social sciences, developing ‘the art of reflection’ targeting critical thinking, creativity, problem-analysis, and responsibility (also see Schön 1983), and insights into research-strategies in inter-and transdisciplinary research. For the multi-disciplinary teacher-team in our educational-design team, this new concept, how to work with the accompanying CM methodology and understand the underlying philosophical insights is exciting and challenging: "this is a completely new paradigm of what scientific inquiry is and our roles as teachers."

5 CONCLUDING REMARKS

The University of Twente recently developed a challenge-based learning (CBL) minor called *Intelligence, creativity, and responsible technological innovation in societal transformations* (ICR&TIST). This interdisciplinary program aims to cultivate scientific research skills in complex socio-technological problem-solving contexts. The educational design of the minor incorporates the engineering paradigm of science and draws on experiences with the conceptual modelling approach in project-based learning (PjBL).

The current problem is that scientific research training typically focuses on academic contexts, aligned with the physics paradigm of science. However, real-world problem-solving requires the ability to produce relevant, reliable, and understandable knowledge in concrete problem contexts, utilizing the full range of scientific resources available. Additionally, socio-technological problems necessitate trans- and interdisciplinary research, which is intellectually challenging (Boon 2020b).

The goal of the CBL minor is to foster students' trans- and interdisciplinary research skills, with a particular emphasis on interdisciplinary research skills (cf., Van den Beemt et al. 2020, Boon and Van Baalen 2019, Boon 2020b). Existing interdisciplinary PjBL and CBL education primarily focuses on scientific content and professional skills development, with limited support for promoting interdisciplinary research skills (Kuiphuis-Aagten et al. 2019). To address this gap, it is crucial to scaffold students development of higher-order thinking skills required for understanding and conducting scientific research.

A key pedagogical insight is that students struggle to apply abstract knowledge in concrete settings due to the physics paradigm's emphasis on true and justified knowledge. In contrast, the engineering paradigm highlights the application of scientific knowledge in problem-solving contexts and the understanding of how knowledge is *constructed*. Therefore, it is essential to prioritize the development of scientific thinking skills over the conveyance of scientific content. Students with these skills can acquire knowledge independently, prompting teachers to reflect on their contribution to students' scientific thinking skills.

Another insight is that both students and teachers are influenced by the physics paradigm, shaping their beliefs and attitudes about teaching and learning. Paradigm shifts, as described by Kuhn, are challenging and require time. Redesigning education using the conceptual modelling approach necessitates creating awareness of paradigms among teachers and students.

The design process of the ICR&TIST minor involved workshops with the teacher team, where strategies such as reflecting on crucial learning experiences were employed. Teachers' beliefs about scientific research and education were interpreted from the physics versus engineering paradigm to increase awareness of paradigms. This process facilitated the development of shared understandings and led to the joint creation of micromodules, aiming to promote scientific thinking skills related to research and measurement methods, including several types of reflection skills.

Educational research on the pilot of this minor is ongoing, but initial findings indicate that teachers found the approach inspiring, experiencing a paradigm shift in their understanding of scientific inquiry and their role as teachers. Students quickly adapted to the new mindset, finding it exciting and liberating. They realized the potential to develop their higher-order thinking skills actively. Scaffolding the development of scientific research and thinking skills based on the engineering paradigm proved successful, although there is room for improvement and further research is needed to identify and address students' obstacles.

In conclusion, experiences in education and insights into the scientific research required for academically trained engineers highlight the need for the development of interdisciplinary research skills to tackle complex socio-technological issues. Conceptual modelling serves as an overarching skill encompassing various other skills, and a scaffold has been developed to facilitate the learning process. The new educational approaches have shown positive results and garnered appreciation from students and teachers. However, students still face challenges in developing the higher-order thinking skills crucial for scientific research. Further research is necessary to identify and address these obstacles, ensuring the effective support of students in becoming creative and responsible researchers, thereby enhancing the quality of academic engineering education.

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ENTREPRENEURSHIP EDUCATION: CREATING A POSITIVE ADRENALINE

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***Conference Key Areas**: Engagement with Industry and Innovation - Innovative Teaching and Learning Methods*
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ABSTRACT

A method to develop Entrepreneurship Education in any regular Engineering course is presented. The method is based in a team of students working on the description of the idea for the development of a real start-up using a structured approach trained by a business advisor and by the teacher. The team analyses the problem, the potential market, the solution, the development and the financing challenges of the start-up. The team works the Case development along an Engineering Course related with the technology of the start-up. The dedication of each student to the Case development is 25 hours, working along the different phases of the analysis and synthesis, mentored by the business advisor and the teacher. The added value of the experience is based on: first, the preparation and development of a 1 hour interview of the student team with one of the founders of the company, usually the CEO; second, a weekly validation of the technological value proposition with the business advisor, as part of the analysis. Along with the interview, the student team will consolidate their findings and debate with the CEO about their own ideas, being a process full of positive adrenaline and creating a very significant engagement along the whole course. The approach has been tested in two academic years, working 4 cases with the collaboration of 4 start-ups of EIT InnoEnergy. The results of the student surveys demonstrate the validity and engagement level of the approach.

1 INTRODUCTION

1.1 The objective that is addressed

This paper is aligned with the objectives of the European Institute of Innovation & Technology (EIT), a body of the European Union, and the ambition to create a positive impact for our society. An extract of the EIT Vision: “...is to become the leading European initiative that empowers innovators and entrepreneurs to develop world-class solutions to societal challenges and creates growth and skilled jobs.”

The paper is focused on developing a new method for entrepreneurship education, capable of generating more and better impact in the creation of start-ups, even in the short term. The new method that is presented here has been developed because of the opportunities generated by the collaboration of the authors and EIT InnoEnergy, an alliance that incorporated companies, start-ups, universities, research centres, business schools, business advisors and more stakeholders.

1.2 The context for the development

The topic of entrepreneurship education has attracted a lot of attention and has generated significant contributions in recent years. A fundamental view about the nature of entrepreneurship and the skills of an entrepreneur is stated by (Gartner

1988): an entrepreneur is characterised for creating organisations. A comprehensive review of methods and approaches in entrepreneurship education is given in (Gartner and Vesper 1994). The “standard” course includes elements such as business model writing, speakers, readings and cases. All in all, offering basic tools and a number of practical experiences to create background and developing skills. Frequently, judging panels including outside professionals assess the work of the students.

(Liñán and Fayolle 2015) deals with a key factor recently identified in entrepreneurship education: entrepreneurial intention. The research highlights five factors: the model, the influence of personal variables, entrepreneurship education, the context, the entrepreneurial process and the intention. (Kirby 2004) states about the relevance of educating “for” entrepreneurship, instead of educating “about” entrepreneurship, the ultimate goal is to focus on student centered approaches.

When talking about student centered methods, a fundamental work to be considered is (Dewey 1986). The essence of the proposal is to use direct experience as the fundamental engaging approach in education.

A relevant contribution on the student centered approach applied to entrepreneurship education is (Robinson, Neergaard, Tanggaard and Krueger 2016). This paper, based on an ethnographic approach, focuses on the pre-foundation phase, as original when compared with the typical approach analysing the post-foundation phase.

The method presented in this paper integrates the different approaches in the literature listed above with the specific opportunities of the EIT InnoEnergy alliance.

2 METHODOLOGY

2.1 Description of the method

The method presented in this paper incorporates some fundamental principles identified in previous research and own contributions:

1. The capacity of the students to become entrepreneurs (create an organisation) after the experience in the course.
2. The course should work on basic topics like the analysis and synthesis of a business model and similar tools.
3. Outside professionals will add a relevant perspective in the course.
4. Entrepreneurial intention of the students should be fostered.
5. The method should be oriented to action (student centered education) rather than to entrepreneurial theory.
6. The method should include the pre-foundation and the post-foundation analysis of an entrepreneurial idea.

Taking into account the previous 6 principles, the analysis of the actors that participate in the experience follows:

- The Students. MSc students, with a technical background and fundamental skills already developed during the Bachelor and during the previous courses.
- The Teacher. Specialised in the topic of the MSc programme and with experience in Entrepreneurship Education, both from the theoretical side and the performance side (knowledgeable about start-up cases).
- The Business Advisor. An outside professional that complements the knowledge by the Teacher, providing a deep contextualization about the business aspects.
- The Start-up. A real start-up participates in the assignment.

In summary, the assignment for the students is built around the analysis of the pre-foundation and the synthesis or development (post-foundation) of a real start-up. Everything working in a team and in collaboration with the teacher and the business advisor, in a professional way. The synthesis of the start-up case is elaborated by the students, with proposals about the start-up development. An interview of the students with the start-up CEO (or other C-level positions) is arranged in such a way that a consolidation of the case is made. A final elaboration of the start-up case is done by the students consolidating their findings after the interaction with the CEO during the interview. The assignment is described in the flow diagram of Figure 1.

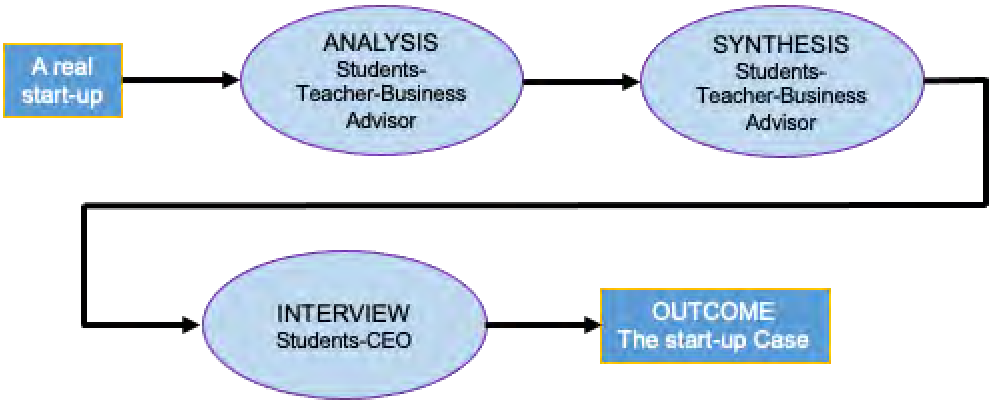

Fig. 1. Flow diagram of the assignment.

The explanation of the interactions among the actors is graphically shown in Figure 2. The teacher and the business advisor interact 3 times with the start-up: first, before starting the semester, for the global preparation of the assignment; second, for the preparation of the interview students-CEO and, third, for a post semester wrap up.

The students interact once per week with the business advisor and the teacher presenting their current work, with a later debate. The students interact additionally once per week with the teacher, for clearing technological concepts. The students have only one interaction with the start-up, for the interview with the CEO.

Finally, the teacher and the business advisor run mutual interactions before the semester (preparation), during the semester (execution) and after the semester (wrap up).

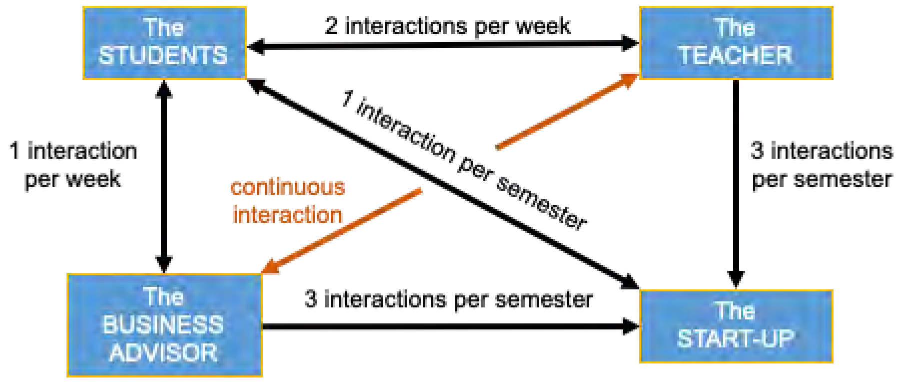

Fig. 2. The interactions among the actors in the assignment.

The content of the assignment is shown in a block diagram format in Figure 3.

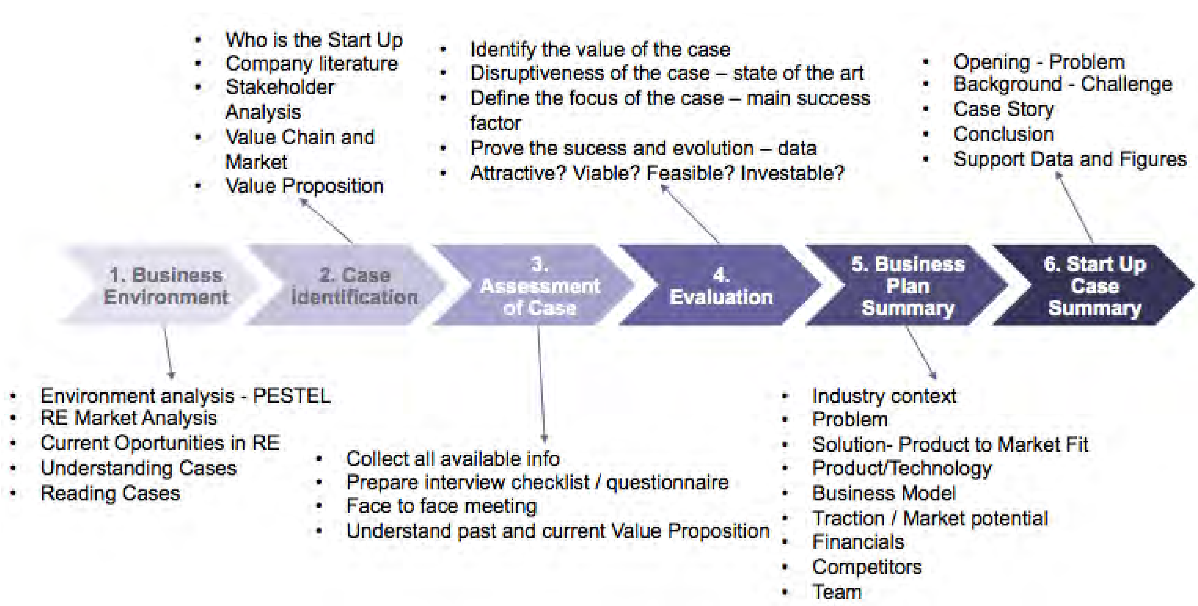

Fig. 3. Block diagram of the assignment content.

The block diagram shows the 6 steps for making feasible that all the objectives of the assignment are completed:

1. Business Environment: pre-development of the start-up, analysing the context.
2. Case Identification. This step is also part of the pre-development. The students work in detail on the value proposition of the start-up.
3. Assessment of Case. Progress in the analysis of the start-up and preparation of the interview with the CEO.

4. Evaluation. Completing the analysis of the start-up and running the interview with the CEO.
5. Business Plan Summary. After the interview with the CEO, the business plan of the start-up looks clear.
6. Case summary. Wrapping-up all the analysis and synthesis of the assignment.

The 6 steps along with the bullet points in Figure 3 constitute a checklist of all the points to be worked in the analysis.

2.2 Implementation

The method has been implemented in MSc RENE (Master`s in Renewable Energy), one of the programmes of the EIT InnoEnergy Master School. This programme is awarded with the EIT Label, under the quality seal of the EIT Quality Assurance and Learning Enhancement (EIT QALE). The University is UPC-BarcelonaTech, under the umbrella of the Master's degree in Energy Engineering, accredited in Spain by the Ministry of Education's degree register.

The course where the method is applied is "Renewable Energy Technology", a mandatory course in the semester 1 of the programme. This course is planned for a duration of 1 semester and a student load of 5 ECTS, equivalent to 125 hours of work per student. The method is implemented as the only assignment of the course for the student team. For making the load of the assignment proportional to the size of the course, a load of 25 hours per student has been chosen. Subsequently, the number of students in the team is designed to have a significant capacity to run the analysis and synthesis of the start-up case. The optimal number of students in the team is 4-6, since then an amount of 100-150 hours is available globally. The design of the method based in student teams shows different benefits:

- The amount of work available to generate significant results is matching the needs of the intended analysis.
- The work of the students in teams makes possible to improve the skills related with team building.
- Particularly, a number of even students in the team is preferred, since it forces the decision making by agreement instead of by voting, which is considered an additional benefit of the team building training.

The first week of the course, the business advisor and the teacher run a kick-off session, explaining how the assignment is organised and key topics about the analysis and synthesis of a start-up, such as success factors of start-ups, a short description of the start-up and some tools to analyse energy market scenarios.

From this point on, the student team runs the different phases of the process depicted in Figure 3 with the continuous mentoring of the teacher. One presentation per week is done by the student team.

The key moment during the assignment is the interview with the start-up CEO. The interview is led by the student team that has made a previous preparation with the business advisor and the teacher, who are also present during the interview.

The grading for 80% of the course is done by the teacher consulting the opinion of the business advisor. Every phase of the assignment is graded: weekly presentations, preparation of the CEO interview, CEO interview, case report. At the end of the course, a peer evaluation is done, asking all the students to grade their colleagues and themselves. This mark weighs 20 % of the final grade. This grading method is motivating in the sense that keeps the student team concentrated in performing very well with the start-up case assignment.

3 RESULTS

3.1 Assignments done so far

The teacher and the business advisor have collaborated with EIT InnoEnergy in identifying start-ups in their portfolio that are thematically interesting for the scope of the course where the assignment is done and also attractive for the students.

The attractiveness for the students has been chosen because of addressing an interesting technology in the field of renewable energy and because of having a high level of innovation (architectural innovation, disruptive innovation or radical innovation). See (Christensen 2013).

An initial pilot with only one company was held in the autumn semester of academic year 2021-22 with Flexidao. The interview was conducted with Joan Collell, CGO, and Emanuele Rossi, Innovation and Product Manager. Flexidao has invented a renewable energy monitoring software. Four students participated in this assignment.

After the success of the pilot, 3 more cases were run in the autumn semester of academic year 2022-23. The companies and the number of students were:

- BeePlanet, a second life for EV batteries in renewable energy facilities. Four students worked on this case. Jon Asin, CEO, participated in the interview.
- Ezzing, optimises the whole value chain of stakeholders in solar PV installations. Five students worked on this case. Víctor Sancho, CEO, and Blanca Cidoncha, Head of Business Development, participated in the interview.
- X1Wind, has patented and developed a disruptive floating wind system for offshore wind turbines. Four students worked on this case. Alex Raventós, CEO, participated in the interview.

3.2 Results of the student surveys

Globally, 17 students have participated in the 4 editions of the start-up case assignment. They are coming from 10 countries in 4 continents. This means a variety of perspectives in the class. Table 1 shows a summary of the answers in the student surveys, designed to assess if the new method to develop entrepreneurship education presented in this paper is valuable.

Qualitatively, the results show the high level of engagement of the students with the method: professional experience with the business advisor and the start-up CEO, acquiring knowledge contextualised with business, knowing the essentials to become entrepreneurs, practising soft skills in team building and communication. Definitely, the experience of the interview with the CEO shows the best results and it was additionally identified as the key element of the method when the students were informally asked in the lecture room if running the method without such an interview could be equally valuable. The answer was clear: definitely, not. This is the “positive adrenaline”.

Table 1. Summary of the student surveys answers

4 CONCLUSIONS AND ACKNOWLEDGMENTS

A new method to develop entrepreneurship education in a student centered approach has been presented. The method is valid for any course in an engineering master and also facilitates the development of soft skills by the students.

The combination of the work of the teacher and a business advisor has proven to be very effective to create a strong engagement with the student teams. The business advisor shows a relevant level of empowerment, because of the practical experience in developing businesses.

The idea of co-working the analysis and synthesis of a real start-up case among the student team, the teacher and the business advisor is certainly strong. And, very specially, the level of “positive adrenaline” created because of the milestone defined by the interview with the start-up CEO is really high. Quantitatively and qualitatively, the students agree on how differential and engaging this experience is (surveys in Table 1).

The duration of the assignment is 25 hours per student and the work in a team makes feasible to get relevant results and is positively assessed by the students.

The method has the potential to be extended as an assignment in many engineering courses: the key point is in collaborating with a business advisor and with a start-up. Certainly this is an external element to the teacher and may be a limitation for the applicability.

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ENGINEERING SOCIETY: THE ROLE OF INTERSECTIONAL GENDER AND DIVERSITY STUDIES FOR A SUSTAINABLE TRANSFORMATION ON THE CASE OF INTERDISCIPLINARY ENGINEERING EDUCATION

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***Conference Key Areas**: Addressing the challenges of Climate Change and Sustainability, Equality Diversity and Inclusion in Engineering Education*
***Keywords**: sustainability, gender, diversity, intersectional, engineering education*

ABSTRACT

Technological innovations are impacting societies in manifold ways and can accelerate a transformation toward sustainability. To enable a sustainable transformation through engineering, engineers educated to create technological solutions for global challenges must be educated in sustainability principles as postulated under 'Education for Sustainable Development' (ESD) in the Agenda for Sustainable Development. In technological fields, the ecological, as well as the economical perspective of sustainability, are often addressed, but as recent research has highlighted, sustainability needs to be addressed holistically; this means including the social dimension to a greater degree and applying an intersectional understanding of gender and diversity throughout all spheres of sustainability. It is therefore imperative for engineering students to learn and understand where gender and diversity are necessary for sustainability, how diversity dimensions intersect, and which intersections are particularly relevant for novel technologies and societal development. Accordingly, this paper sketches an interdisciplinary approach for applying intersectional gender and diversity studies in the context of a sustainable transformation of engineering education. We draw on our experience of having educated engineers accordingly for a decade at the GDI (Gender and Diversity in Engineering) at RWTH Aachen University. Selected examples from our teaching practice are presented and six general maxims are deduced that can make engineering education more sustainability-oriented, inclusive, and diverse. As we will conclude, fostering innovative and inclusive engineering education needs interdisciplinary teams adhering to our proposed six maxims to accelerate a gender- and diversity-sensitive sustainable transformation.

1 INTRODUCTION

Considering complex global challenges such as sustainable development, engineering education should transgress its disciplinary boundaries together with its classical reductionist focus on mere technical problem-solving (Takala and Korhonen-Yrjänheikki 2019; Sigahi et al. 2023). Accordingly, such challenges call for a new type of interdisciplinary educated engineers (Van den Beemt et al. 2020) that can cope with complexities, ambiguities, or uncertainties (Takala and Korhonen-Yrjänheikki 2019; Sigahi et al. 2023).

This is in line with the United Nations stressing that engineering, as an essential factor influencing sustainability, should integrate a gender-sensitive perspective of diversity and inclusion to foster a sustainable development that goes beyond a mere focus on ecological and economic factors (United Nations 2021). Correspondingly, researchers, educators, and practitioners must be enabled to discover and deal with complex intersections between gender and engineering as well as gender and sustainability (Khalikova, Jin, and Chopra 2021). Further, this signifies the need for educational initiatives that foster the development of critically reflective and socially responsible engineers (Steuer-Dankert et al. 2019). While practically-oriented research on engineering education has suggested how intersectional gender and diversity studies can improve engineering education (Leicht-Scholten 2019), there is less research focusing on how to integrate the intersection between gender and sustainability in the context of engineering education.

Having applied intersectional gender studies along with a broad understanding of sustainability in engineering education for more than a decade at the Institute Gender and Diversity in Engineering (GDI) at RWTH Aachen University, in this paper, we contribute to closing this gap by proposing six maxims derived from literature and our practical experience to lay the foundation for future developments in sustainability education.

2 METHODOLOGY

As a starting point, we will outline selected research findings on the relationship between gender, engineering, and sustainability that are to be considered for a holistic education that acknowledges intersectionality as a connecting anchor between these topics. After this, we briefly present two exemplary educational approaches that already put these intersectional and holistic understandings into practice. We then deduce six generalized maxims on how to apply an intersectional sustainability perspective to engineering education.

3 THEORETICAL BACKGROUND: ENGINEERING EDUCATION AND THE INTERSECTION OF GENDER AND SUSTAINABILITY

As we highlighted in a previous paper on the contribution of gender research to engineering education (Leicht-Scholten 2019) and illustrated referencing our teaching concept of “Expanding Engineering Limits” (Steuer-Dankert et al. 2019) developed in cooperation with Stanford University, integrating a perspective of intersectional gender studies into engineering education fosters a form of critical reflexivity that allows students to understand sustainability holistically. To reach this, students must, in the first place, develop an understanding of the intersections of gender, understood as socially constructed roles, behaviors, and expectations, that are enacted based on culturally produced ideas of being male or female (Gildemeister 2010), and engineering. Students' development of holistic perspectives profits from learning about topics such as masculine-coded engineering cultures (Faulkner 2000), identities (Cech 2015), artifacts (Cockburn and Ormrod 1993), and processes (Male et al. 2018), that are prevalent in the context of engineering (Leicht-Scholten 2019) and that derive from the gendered culture of society in general (Carberry and Baker 2018). In doing so, students reflect on how these gendered realities generate privileges for white able-bodied heterosexual men in engineering cultures (Cech 2022). Accordingly, students discover that this not only leads to an exclusionary and often discriminatory educational and professional culture for female or other marginalized groups of engineers but also limits innovations that are needed to foster sustainable development of technology and society (Schiebinger et al. 2011-2020). To develop this kind of holistic understanding, students need a fundamental knowledge of the concept of *intersectionality* (Crenshaw 1991). This knowledge of intersectionality can be applied as a tool to recognize that different categories of social identities, such as race, gender, class, ability, and sexual orientation, intersect and create unique experiences of oppression and privilege (Crenshaw 1991) in the context of engineering (True-Funk et al. 2021) and sustainability (Khalikova, Jin, and Chopra 2021). With this at hand, students are enabled to apply a holistic understanding of sustainability that includes an intersectional understanding of gender and diversity, how gender and other intersecting identities (such as race, class, and sexual orientation) intersect with environmental sustainability, and how these intersections can be addressed comprehensively and effectively. This intersectional sustainability perspective acknowledges that people can experience multiple forms of oppression and discrimination simultaneously and that these intersecting experiences and identities must be considered when sustainability is the goal (Khalikova, Jin, and Chopra 2021).

Recent research has highlighted how gender and other factors intersect with sustainability. For example, women and other marginalized groups often bear a disproportionate burden of the negative impacts of environmental degradation and climate change, such as food insecurity, displacement, and health problems (Odrowaz-Coates 2021). Women are also often excluded from decision-making processes related to sustainability and conservation (Odrowaz-Coates 2021). Thinking of sustainability in terms of intersectionality requires acknowledging and addressing the interactions between societal inequalities and environmental degradation. This involves understanding that environmental problems, such as climate change and biodiversity loss, disproportionately affect marginalized communities, such as low-income communities and communities of color. At the same time, social justice issues, such as poverty, racism, and gender inequality, can also contribute to environmental degradation (Prati, Cazcarro, and Hazra 2022). Such interdependencies are also becoming increasingly relevant in the context of digital transformation and Artificial intelligence (AI), where intersections between sustainability (Van Wynsberghe 2021), gender, and diversity (Buolamwini and Gebru 2018), are discussed in the context of a sustainable transformation of society and technology.

To address such intersections successfully, an inclusive and holistic sustainability approach that considers the needs and perspectives of diverse stakeholders, including those from marginalized communities, is necessary. This includes recognizing and addressing the differential impacts of environmental degradation and climate change on different groups and incorporating equity and social justice considerations into sustainability policies, practices, and education. Further, it means developing more inclusive and participatory decision-making processes as well as promoting the participation of marginalized groups in decision-making processes (Khalikova, Jin, and Chopra 2021; Odrowaz-Coates 2021).

Consequently, such a holistic perspective should be incorporated into educative approaches to foster the development of responsible engineers that can identify, dissect, and improve complex intersections among engineering, sustainability, and gender, to reach a sustainable future as requested by the United Nations (United Nations 2021).

4 APPLYING GENDER, INTERSECTIONALITY, AND SUSTAINABILITY IN ENGINEERING EDUCATION

The GDI at RWTH Aachen University is unique in Germany in its positioning as a bridging professorship between the Faculty of Civil Engineering and the Faculty of Arts and Humanities (Trujillo et al. 2023). With the research group's experience of having educated engineers for more than a decade, the interdisciplinary team of scientists at the GDI under the leadership of a political scientist focused on Gender and Science and Technology Studies (Gender STS), are pioneers in educating engineering students at the intersection of gender, diversity, engineering, and sustainability (Leicht-Scholten 2019; Decker, Winkens, and Leicht-Scholten 2022).

To offer a practice-oriented perspective deriving from this experience, in the following, we present two examples of engineering education developed and implemented by the GDI.

4.1 Teaching the Fundamentals: Lecture "Engineering and Society"

As stated, engineering education that aims to create technological solutions for global challenges must follow principles of sustainability, as postulated under 'Education for Sustainable Development' (ESD) in the Agenda for Sustainable Development (United Nations 2023). Oftentimes, the idea of sustainability taught focuses strongly on environmental and ecological sustainability but neglects the perspective of social sustainability and intersectionality. However, if engineers are required to build sustainable solutions, they need the tools to understand social structures and communities and to reflect upon the impact of their work on society's environment (Bosen and Leicht-Scholten 2020; Walden et al. 2020). Therefore, engineers must be taught to critically reflect upon the intersectionality of factors of sustainability.

At larger technical universities in Germany engineering education most often includes teacher-centered lectures in front of hundreds of students with little to no active participation and reflection by the students. In contrast to this, the GDI lecture "Engineering and Society", which is a mandatory Bachelor's course attended each year by about 500 engineering students, utilizes participatory concepts of a flipped classroom and blended learning strategies. Through this, students learn about the importance of sustainability, (technology) ethics, and societal structures in their future engineering careers (Decker, Winkens, and Leicht-Scholten 2021). The course has been well-evaluated by students with an interest in the topics for its participatory and intersectional teaching approach to the topics of gender and diversity in connection with engineering and sustainability (Decker, Winkens, and Leicht-Scholten 2022).

4.2 Practicing Inclusion and Diversity in Engineering Education: BIOS

Engineering study courses often are challenging in the first years, with dropout rates among the highest of all courses of study and this disproportionately affects students from non-academic family backgrounds or with less social and cultural capital (Heublein et al. 2017). We propose that an intersectional understanding of sustainability should not just include what is taught but also who is taught. It is therefore imperative to make engineering education more inclusive and diverse.

For this reason, RWTH Aachen University and Aachen University of Applied Sciences jointly launched the cooperation project "A Good Start to Engineering Studies" in 2015. Building on the successful cooperation project, the independent cooperative study course "Civil Engineering with Orientation Semester" (German acronym: BIOS) was introduced in the summer semester of 2020 (GDI n.d.b).

The eight-semester Bachelor's degree course includes one extra semester, providing students with first-hand insights into the civil engineering courses at the two universities and helping them to decide which one fits best for them. Whereas one is a university of applied science with relatively small classes and a practical approach, the technical university of Aachen has larger cohorts, less direct interaction with teachers, and a strong research orientation. Being able to compare the teaching formats, facilitates an individual study decision for the type of university and engineering course for students. It aims to lower the barrier to studying at the university level, which could be particularly valuable for people with a migration background and "first-generation students" (GDI n.d.a).

Following the GDIs approach to teaching the fundamentals as early as possible, BIOS is one of only a few engineering degree programs in Germany that include a mandatory module on responsibly designed technology development.

5 RESULTS – THE GDI-APPROACH

Deriving from scientific literature and our practical experience, we now propose six maxims–that is, propositions generalized from our practical experience in combination with the theoretical state of the art–to follow to successfully apply interdisciplinary educational initiatives on the cross-section of intersectional gender studies, engineering, and sustainability:

1. Anchoring concepts firmly in disciplinary discourses and ensuring interdisciplinary iteration from the beginning–thereby ensuring theoretical integration with the existing disciplinary states of the art and developing new concepts that are more easily translatable into an interdisciplinary practice.

To be able to apply gender studies interdisciplinary, understand where diversity dimensions intersect, and which intersections are especially relevant for the given context, a fundamental understanding of the disciplinary, theoretical discourses on gender and diversity studies and social science methodology is necessary (cf. also Walden et al. 2020; Takala and Korhonen-Yrjänheikki 2019). However, conceptual frameworks only developed disciplinarily often come at the expense of interdisciplinary applicability. This is why we, following, amongst others Van den Beemt et al. (2020); Takala and Korhonen-Yrjänheikki (2019), propose that teams developing concepts to be applied interdisciplinarily should ideally be interdisciplinary from the start and include both disciplinary and scholarly expertise in gender and diversity studies as well as the sciences the concept is developed for. When teams that have fundamental knowledge in social sciences and gender and diversity studies as well as fundamental knowledge in engineering and natural sciences work together on the development and research of concepts, these concepts stand the challenges of interdisciplinary application. This is because interdisciplinary cooperation is already applied in the first sketches of the conceptual frameworks that are then developed further to be taught in interdisciplinary contexts, such as engineering education.

2. Translating disciplinary theoretical concepts into interdisciplinary contexts.

Through iteration in interdisciplinary teams, we translate the theoretical disciplinary state of the art into interdisciplinary contexts. For this, communication in an interdisciplinary team is essential. This is also where empirical data can be disciplinarily evaluated and interdisciplinary validated (cf. for example Bosen, Fuchte, and Leicht-Scholten 2023). This way, there is interdisciplinary communicative validation from the beginning of the conceptual development and even though concepts are still on a theoretical level at this stage, a first round of reviewing intersectionality is also provided, as stereotypes and disciplinary preconceptions are challenged. This step profits from diversity in the team, including as many diversity categories as possible.

3. Example-based communication of these translated concepts–thereby facilitating interdisciplinary understanding.

The theoretical concepts then need to be prepared to be communicated to teams from other disciplines and outside of academia. The challenge here is to not reduce the complexity of the concepts (Sigahi et al. 2023) because we have discovered that this does not lead to satisfactory results (Berg, Steuer-Dankert, and Leicht-Scholten, under review). To facilitate communication or teaching without having to dilute the theoretical concepts, we propose using examples that ideally come from the realm of the target group that is taught these concepts. This way, interdisciplinary compatibility is generated without compromising on the complexity of the taught concepts.

4. Case work–thereby facilitating interdisciplinary understanding and applying the concepts to the relevant interdisciplinary areas.

To illustrate the complexity of theoretical concepts and thereby make them more tangible (Sigahi et al. 2023) as well as to intensify this example-based communication of theoretical concepts, casework has proven a fruitful tool. Cases are examples that are given in greater detail and/or developed by the students themselves. They offer a concrete, multifaceted context for the theoretical concept to be applied by the students (Leicht-Scholten 2019). Students work over a longer period on these cases and develop and shape them. This way, they can shape the cases to their background, hands-on apply the theoretical disciplinary concepts interdisciplinarily, and, thereby, learn to deal with complexities, ambiguities, and uncertainties (also) outside their disciplinary boundaries (Takala and Korhonen-Yrjänheikki 2019; Van den Beemt et al. 2020).

5. Peer-group discussions–thereby encouraging individual reflection and facilitating a low-threshold exchange of the learned concepts in peer groups.

This might be combined with 3. Casework can also be executed as a separate step de-coupled from the casework. Students could be guided by guiding questions or design thinking methods (Leicht-Scholten and Steuer-Dankert 2020). Diversity and heterogeneity of peer groups are preferred and only minimal intervention by the teacher in the discussions at this stage is preferred.

6. Discussion and iteration – thereby re-iterating conceptual framework for new applications but also furthering state-of-the-art discussion in disciplinary contexts.

As a final step, it is imperative to encourage discussions across the peer groups and engage all students in a broader discussion but also to collect feedback so that lecturers may re-evaluate their concepts, starting again with phase 1.

6 DISCUSSION

We proposed a novel practical attempt to bring together research from intersectional gender and diversity studies and sustainability in the context of engineering education, acknowledging that engineering, and gender inclusion, play a crucial role in sustainable development (United Nations 2021; Khalikova, Jin, and Chopra 2021). While there have been attempts to better integrate the social dimension into sustainability discourses (Odrowaz-Coates 2021), there has been no interdisciplinary approach, rooted in both research and practice, that conceptualizes the interdependencies between intersectional gender and diversity studies and sustainability studies in the context of engineering education. Accordingly, our proposed maxims help fill this gap and thus align with the United Nations' call for "new approaches within higher education and, possibly, even a fundamental reconceptualization of teaching and learning" (United Nations 2017, 5) in the context of education on sustainable development.

Our proposed maxims are generic in their current form. While this might limit their scope, it allows for adaptability to different contexts and improvements after application in practice. Correspondingly, their generic outline offers flexibility and adaptability and, therefore, aligns with the demands of fostering reflectivity, creativity, and innovativeness within the development of engineering education (Takala and Korhonen-Yrjänheikki 2019). This becomes apparent in the maxims *4) case-relatedness*, *5) participation,* and *6) discussion or iteration,* since these phases promote, when combined, a reflexive and collaborative hands-on practice demanding and fostering students to develop social skills (Lopes et al. 2015; Bairaktarova and Pilotte 2020).

The maxims *1) anchoring*, *2) translating* and *3) exemplarity* correspond to the demand for inter- and transdisciplinarity in the context of sustainability science and education (United Nations 2017; Van den Beemt et al. 2020). Because they, as also proposed by Sigahi et al. (2023) and Takala and Korhonen-Yrjänheikki (2019), extend the classical disciplinary engineering focus on sustainability by introducing relevant and contextualized insights on an intersectional and interdepended perspective on sustainability, and thereby foster complexity-thinking in a broader sense. This challenges engineering students' tendencies to reduce given issues to, e.g., mere technical aspects (Sigahi et al. 2023) and, accordingly, assists their "develop[ment] from technical problem-solvers to collaborative creators capable of defining relevant questions, and creating solutions, to complex transdisciplinary problems" (Takala and Korhonen-Yrjänheikki 2019, 175f.), such as sustainable development.

Accordingly, the proposed maxims of *1) anchoring*, *2) translating*, *3) exemplarity*, *4) case-relatedness*, *5) participation*, and *6) discussion* or *iteration*, offer guidance to educate engineers on topics of gender and diversity studies and sustainability while contributing to transforming engineering education towards sustainability by assisting the development of interdisciplinary competencies, critical complexity-thinking, adaptability, as well as collaborative social skills.

7 CONCLUSION

To engineer a sustainable and just future, interdisciplinary educational initiatives are needed that use case-based and participatory learning approaches to convey the interdependencies and intersections of gender, engineering, and sustainability. This requires interdisciplinary teams that can develop innovative teaching and learning concepts based on our proposed maxims of *1) anchoring, 2) translating, 3) exemplarity, 4) case-relatedness, 5) participation, and 6) discussion or iteration* as well as further research on the introduced intersections between gender, engineering, and sustainability.

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FORMULATION OF THE FIRIS-P PROFESSIONAL CORE-COMPETENCY FRAMEWORK FOR FLEXIBLE ACADEMIC CURRICULA: THE BIOMEDICAL ENGINEERING PROGRAM

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ABSTRACT

Introduction – How to formulate the goals of an academic educational program in such a way that they reflect the identity of the profession, but at the same time allow the flexibility required for self-responsible and self-directed individual study paths that can initiate lifelong learning and successful interdisciplinary collaboration after graduation? Here, we present a novel competency framework that (1) reflects the identity and academic level of the interdisciplinary Biomedical Engineering (BME) profession, (2) permits the alignment of program intended learning outcomes that accommodate the content of the different specialisation tracks of the BME program and (3) guides students and staff by improved curriculum mapping and optimization.
Methods – We collected input from teaching staff members who are actively practicing their BME profession in the interdisciplinary ecosystem around our university. Using their feedback, we iteratively formulated a set of core competencies that characterize the work and role of the BME professional. We obtained preliminary face-validity by performing curriculum mappings from several courses from BME-

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tracks and by asking feedback from students. Results – The iterations resulted in the FIRIS-P competency framework including five successive core professional competencies of which specified subcompetencies carry the BME identity: (1) Fundamental competencies, (2) Instrumental competencies, (3) Reasoning competencies, (4) Interventional competencies, and (5) Societal competencies. These core professional competencies are completed and supported by transferable Personal competencies. Discussion: Preliminary validation indicates that the FIRIS-P framework carries all three characteristics mentioned above, warranting future evaluation of its merits for education of lifelong learning BME professionals.

1 INTRODUCTION

In our rapidly changing society, facing complex challenges, we need lifelong learning academic professionals who continuously adapt to new circumstances and who can collaborate and contribute in an interdisciplinary context. Our educational programs should respond to that need by providing our students from 'day one' with meaningful guidance and training to take control of their self-directed individual development pathway. A main challenge we face here, is to offer a continuously optimized and flexible educational content that enables our students to gain professional mass and direction on this pathway, but at the same time sufficiently preserves the identity of the profession to ensure the value of the diploma.

1.1 Local Context: Our Biomedical Engineering program

During the last decades, Biomedical Engineering (BME) has evolved from a collection of mono-disciplinary professions with their own specialization towards their application in the medical field, to a fully interdisciplinary profession in its own right. Our Biomedical Engineering educational master program includes four specialisation tracks that are aligned to the research domains of our TechMed institute:

- Biorobotics (BRB) – focusing on the use of mechatronic systems for improved surgical interventions or rehabilitation.
- Imaging and in-vitro diagnostics (IVD) – focusing on visualising the human body and detecting abnormalities in cells and tissues in order to detect diseases and monitor health.
- Physiological signals and Systems (PSS) – focusing on the observation and modulation of human body systems (e.g. sensory, motor and endocrine), which can be dysfunctional due to trauma or disease.
- Bioengineering Technologies (BET) – focusing on technologies that mimic or restore the function of diseased organs and damaged tissues, such as organs-on-chips or tumours-on-chips and targeted (nano)medicine.

As the Body of Knowledge and Skills (BoKS) differs largely between the tracks, each track has a tailored program content to prepare students for their final Masters assignment in one of the track related research groups. Our Techmed researchers – operating in the entrepreneurial ecosystem of our university - are also core teachers of many courses and actively participate in shaping the BME curriculum.

1.2 Problem statement and objectives

For the formulation of program goals and design of curricula, numerous competency frameworks have been developed, mostly to ensure that educational programs meet accreditation standards. Many frameworks show a clustering of (sub)competencies in competency areas or core-competencies, e.g. constructed from accreditation standards (Lu et al. 2019) or, the other way around, based on results from competence research (May and Terkowsky 2014) and subsequently validated using accreditation standards.

The Dutch accreditation system has adopted the Meijer's criteria for academic bachelor's and master's curricula (Meijers et al. 2005) as assessment criteria for the accreditation of engineering programs. These criteria are also formulated as a framework of competencies that university graduates should have at the start of their professional career (see textbox 1 for their clustering in core-competencies). In our Biomedical Engineering program we have aligned the final program goals to the Meijer's criteria. Although this approach supports guarding of the academic level of training within the program, the identity and core competencies of the BME profession are only implicitly reflected in the clustering and generic formulations of the Meijer's based competencies. This makes it more difficult to identify how available or required courses in the different specialization tracks contribute to the program goals, which in turn hampers both the optimization of the program content by staff and the targeted and flexible use of the program content by students. Not surprisingly, we observe that our program goals primarily play a prominent role in the accredication cycle of programs and are less actively used in curriculum design or for guiding self-directed learning by students.

Textbox 1: The Meijers Criteria for Academic Bachelor's and Master's Curricula [1]:
A university graduate
1. is competent in one or more scientific disciplines
2. is competent in doing research
3. is competent in designing
4. has a scientific approach
5. possesses basic intellectual skills
6. is competent in co-operating and communicating
7. takes account of the temporal and the social context.

On the other hand, (Degré and Castilo-Colaux 2016) argued that competency frameworks can be a powerful tool for academic staff to collaboratively design their courses as a coherent part of the curriculum, for students to be more involved in their education and to choose their studypath and for the dialog with the professional field. Indeed, if we expect students to prepare for self-directed lifelong learning by deriving a BME-specific dot on their horizon and by determining their own study path, we need clearly formulated program intended learning outcomes that (1) are aligned with an instructive competency framework that explicitly reflects the identity of the BME profession well beyond graduation, instead of focusing on entry competencies, and (2) can accommodate the BoKS and content of courses in the different specialisation tracks of the BME program in a straightforward way. In our opinion, to fulfill the cohesive, instructive and communicative roles as proposed by Degré and Castilo-Colaux, a competency framework should not only adequately accommodate the 'what' of all competencies, but also should feature a clustering into competency areas that coherently reflects the ‘how’ of successful academic professional contributions to society: It should facilitate teachers to share the narratives of the successes (and failures) in their professional practices and shape both the content and the pedagogical approach in their education. It should also facilitate students to recognize the combined functionality of these core competences in the work of professionals (inside and outside academia), to choose role models and to develop the narrative of their own career. In our experience, the Meijers criteria and many other competency frameworks insufficiently fulfill this requirement, which made us initiate the development of a framework with a more functional clustering.

2 METHODOLOGY

2.1 Formulation of the competency framework

We collected input from teaching staff members who are actively practicing their BME profession in the interdisciplinary ecosystem around our university. We took the consensus on our mission as biomedical engineers, as posted on our educational website at that time (textbox 2) as a starting point and we reflected on how we as biomedical engineers use fundamental scientific knowledge to develop technology and apply this technology to create products that solve healthcare problems. By focussing on the activities (verbs) mentioned in the mission statement and connecting these to the content of our very different biomedical engineering practices, we then discussed how we could use this narrative to present the BME identity more explicitly and instructively in a clustering of competencies that can comprehensively accommodate the content of the BME specialisation tracks.

Textbox 2: Our BME mission statement

Biomedical Engineering is an interdisciplinary field, combining engineering disciplines and natural and life sciences. By integrating scientific and engineering concepts and methodology the Biomedical Engineer works to increase scientific knowledge and solve health care problems, by:
1) acquiring new knowledge of living systems through continuous innovation and substantive application of experimental, analytical, and design techniques.
2) design and development of new devices, algorithms, processes and systems to advance Medical Technology in health care.
3) solving health care problems through purposeful context-driven problem solving;
4) implementing solutions using excellent cross-disciplinary communication and collaboration.

2.2 Program intended learning outcomes and curriculum mapping

We tested if the new competency framework permits alignment of program goals that clearly describe the abilities of the student at graduation, in terms of the content of the BME specialisation tracks. At each component of the framework, we formulated track specific intended learning outcomes (TILOs) for each track. Subsequently, we tested if the new framework permits mapping of the content of courses in the BME program offer to the components of the framework.

2.3 Student responses

To get a first impression of the instructional value of the new competency framework and the merits for self-directed learning, the competency framework was provided and explained to students (N=60: 12 BET, 13 PSS, 12 IVD, 23 BRB) of the compulsory MSc-BME startercourse ‘Technology for Health’. Subsequenly, the students were asked to recognize these competences in the work of TechMed researchers. As an individual assignment, each student was asked to report the result of self-reflection, based on the following questions:

- Expertise: Which of the BME subcompetencies do you like or consider as one of your strengths? Answer options: Strong, somewhat, not my expertise.
- Ambition: Which of the BME subcompetencies do you want to acquire before you graduate? Answer options: Need this, done this, not for me.
- Importance: Which of the BME subcompetencies are important in the professional field you envision yourself working? Answer options: Important, moderately important, not important.
- Program offer: Which of the BME subcompetencies are in your opinion poorly or not represented in your educational program or courses offered at our university? Answer options: Need more, sufficient, too much.

Besides obtaining these nominal reponses, students were asked to briefly motivate their ratings or provide examples (data not reported here).

3 RESULTS

3.1 The FIRIS-P Competency framework

Our reflective discussions and iterations resulted in the FIRIS-P competency framework including five interconnected core academic professional competencies of which specified subcompetencies carry the BME identity (see also Fig. 1). Subsequently, these core professional competencies were completed by adding transferable Personal competencies. Also an explanation to students was formulated (not presented here).

3.2 Program intended learning outcomes and curriculum mapping

In Fig. 2, the use of FIRIS-P for program intented learning outcomes and curriculum mapping is depicted. For all subcompetencies, track specific intended learning outcomes (TILOs) can be formulated that specify the BoKS that should be mastered at graduation. By formulating different TILOs for different specialization tracks (see Textbox 3 for an example), the contribution of track content to the BME identity carrying competencies can be specified, despite differences between the tracks. Subsequently, the mapping of (desired) course content contributing to the attainment of TILOs becomes straightforward.

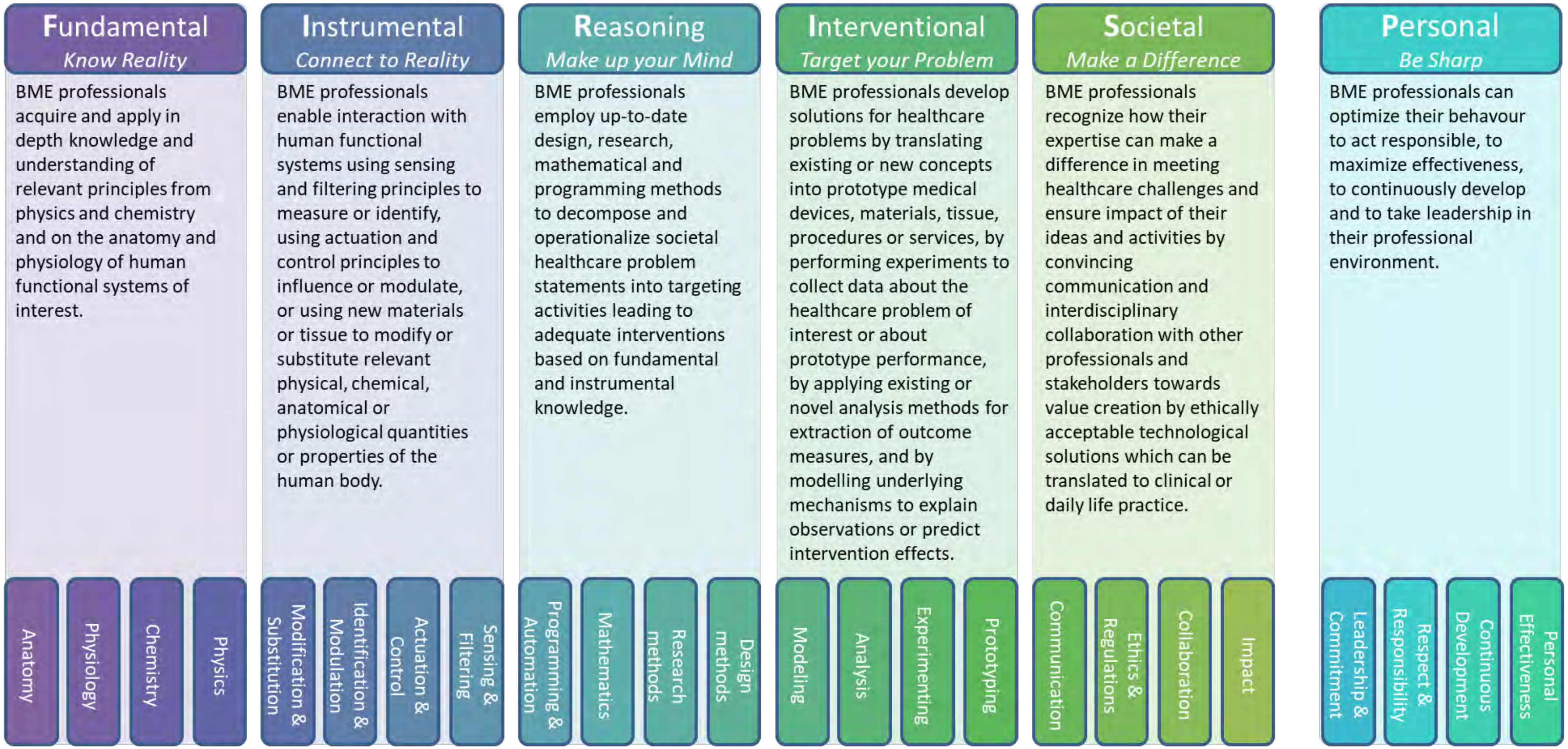

Fig. 1. The FIRIS-P competency framework, in which the identity of the BME profession is made explicit in five core professional competencies (FIRIS), representing the way engineers impact society by interventional activities in which they thoughtfully employ fundamental and instrumental knowledge and skills. At each core competency, BME specific subcompetencies are formulated, linking the BME identity to relevant BoKS content. The FIRIS part is completed by Personal competencies, describing transferable knowledge, skills and attitudes needed for sustained effectiveness as a professional.

Textbox 3: Example of track specific program intended learning outcomes, connecting concrete BoKS to the FIRIS-P subcompetency Sensing & Filtering (Instrumental competencies)
Biorobotics - The student can employ physical and chemical principles to obtain analog and digital signals which are sensitive to relevant quantities of human body and/or robotic systems of interest and can employ analog and digital signal processing methods to increase the specificity of these signals towards the human and robotic system behavior of interest.
Physiological signals and systems - The student can employ physical and chemical principles to obtain analog and digital signals which are sensitive to relevant quantities of human body systems of interest and can employ analog and digital signal processing methods to increase the specificity of these signals towards the human system behavior of interest.
Bioengineering technologies - The student can employ biophysical, optical and molecular biological techniques to study the function of human cells and tissues in healthy and diseased states.
Imaging and in-vitro diagnostics - The student can employ physical and chemical principles to obtain spatiotemporal signals which are sensitive to relevant changes in human anatomy of interest and can employ analog and digital signal processing methods to visualize these signals and increase their specificity towards specific disease progression.

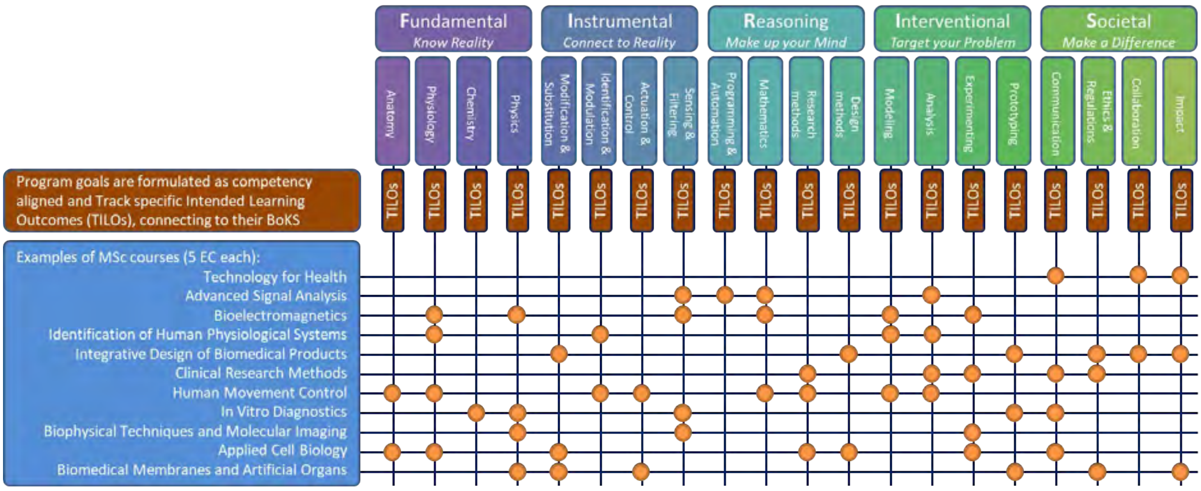

Fig. 2 The connection between the FIRIS-P framework and the BME BoKS can be realized through the formulation of Track specific program Intended Learning outcomes (TILOs, see textbox 3 for examples). To illustrate curriculum mapping, contributions from several courses from the BME program offer to the FIRIS-P aligned TILOs are depicted.

Meijer's Criteria FIRIS-P	Fundamental	Instrumental	Reasoning	Interventional	Societal	Personal
1. Is competent in one or more scientific disciplines	☑	☑	☑	☑	☑	
2. Is competent in doing research			☑	☑		
3. Is competent in designing			☑	☑		
4. Has a scientific approach	☑	☑	☑	☑		
5. Possesses basic intellectual skills			☑	☑	☑	☑
6. Is competent in co-operating and communicating					☑	☑
7. Takes account of the temporal and the social context					☑	☑

Fig. 3 Preliminary mapping the FIRIS-P competency framework on the Meijer's criteria.

3.3 Accreditation aspects

Of course, also with FIRIS-P aligned program intended learning outcomes our BME program should still meet the accreditation criteria, in our case the Meijer's criteria. In Fig. 3 is depicted how FIRIS-P core-competencies (preliminary mapping only, subcompetencies omitted for brevity) contribute to meeting the Meijer's criteria. All Meijer's criteria are covered by multiple FIRIS-P competencies, showing where these criteria are relevant in the BME profession.

3.4 Student's response

After explanation of the FIRIS-P framework and practicing with recognizing the competencies in the work of TechMed researchers, the students reported their self-reflections on each subcompetency of the FIRIS-P framework (see Fig. 4). Most students reported strong or moderate expertise on all subcompetences, as obtained during their preceeding BSc program. Some students reported subcompetencies on which they rated their expertise as (almost) 'none'. Similarly, the students reported varying ambitions to learn more and estimated importance of subcompetences for their future professional practice. Finally, the students reported the offered program content on each subcompetency as overall 'sufficient', but also expressed their need for more elaborate offer, e.g. on programming & automation and prototyping. It should be noted that the students reports may depend on the track they are following (not analysed here): For example, fundamental knowledge of chemistry is less prominent in tracks other than Bioengineering technologies (12 students), which might explain the reported lack of expertise, ambition and importance.

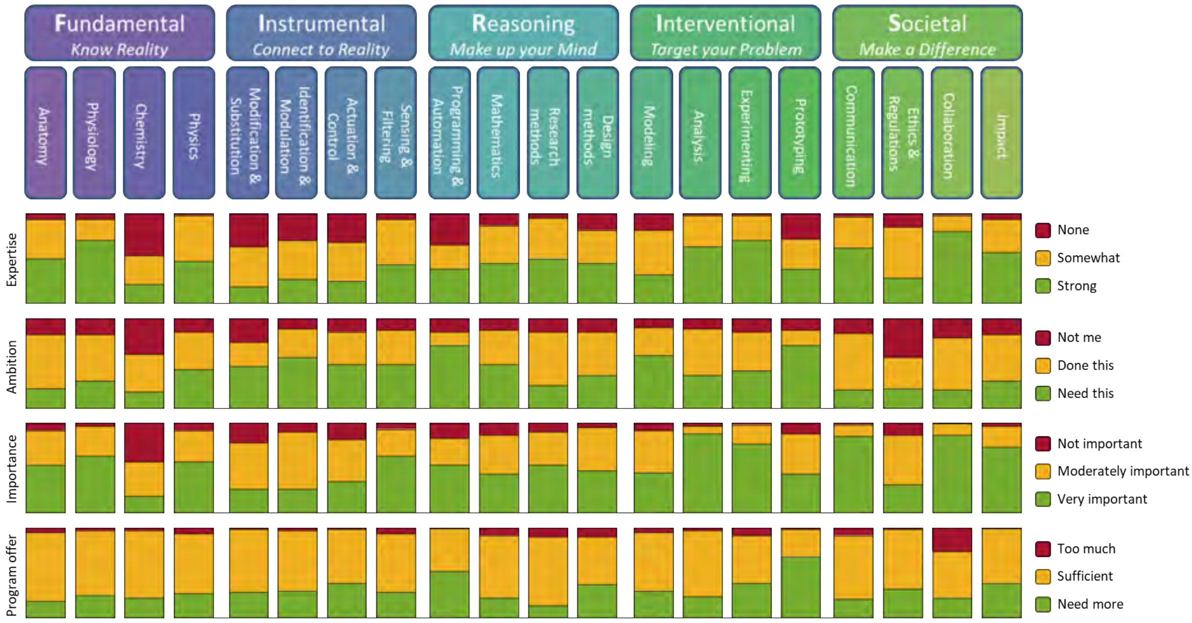

Fig. 4 Student self-reflections using the FIRIS subcompetencies. For each subcompetency, 60 MSc-BME students reported their level of expertise, their ambition to learn more, the estimated importance in their future professional practice and the learning opportunities offered by the program or at our university.

4 DISCUSSION

We aimed to formulate a novel competency framework that (1) reflects the identity and academic level of the interdisciplinary Biomedical Engineering (BME) profession, (2) permits the alignment of program intended learning outcomes that accommodate the content of the different specialisation tracks of the BME program and (3) guides students and staff by improved curriculum mapping and optimization. The resulting FIRIS-P framework and the preliminary validation we present here is stil work in progress, but can be of interest beyond the BME program for which FIRIS-P was developed.

4.1 Methodological aspects

We should note that the FIRIS-P framework is formulated in a local reflective process at our university. A direct benefit of this approach is the ownership of the formulations that arises with the staff contributing to the process, which enhances the teaching of FIRIS-P to students and – practice what you preach – supports being a role-model. Although the involved staff consists of active BME researchers operating in the entrepreneurial ecosystem of our university, the risk of being biased towards the content and identity of the BME professional practice cannot be fully excluded. Hence, it is recommended to validate and refine the FIRIS-P framework also with stakeholders from outside our direct ecosystem and the wider educational community. The initial validation steps we performed show some face validity concerning the connection to the BoKS of specialisation tracks, straightforward curriculum mapping and fulfilment of accreditation criteria. Furthermore a first impression of the instructional and guiding value of FIRIS-P for self-directed learning of students was obtained. As most of our students enter the Master BME after their BSc BME in our institute, many of them have made an informed choice for a specific specialization track during their 3rd year of the BSc program. This provides some level of understanding (e.g. Bloom’s: apply, SOLO: multistructural) needed for making FIRIS-P based formulations of their learning ambitions and matching these to the program offer. However, this level of understanding should be (and is, in the Technology for Health course) monitored and further increased by active engagement of the students and coaching by teachers and study advisors.

4.2 Merits of the FIRIS-P framework

In our view, a main improvement we reached with the FIRIS-P framework is the more role based clustering of competencies, i.e. a clustering that that more narratively reflects the way in which scientific and technological insights are employed for the benefit of society and that invites students to develop their personal professional narrative during their educational program and future lifelong learning career. The five-plus-one clustering of the FIRIS-P framework is likely to also allow formulation of the ‘professional narrative’ for other engineering, and perhaps even non-engineering academic programs: all (engineering) professions employ their fundamental knowledge and understanding of reality and instruments in reasoned way for impactful targeting of societal needs. If this is indeed the case, this might indicate that active awareness of the FIRIS-P structure might provide students and professionals with a cognitive structure that fosters interdisciplinary collaboration by providing students with a cognitive structure that facilitates the identification of their own disciplinary strengths using the FIRIS-P subtitles (see fig. 1) to find 'common grounds' with other disciplines (see also Claus and Wiese 2019).

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TOWARDS PERCEIVING TEACHING AS A JOINT TASK IN AN INDIVIDUALIZED QUALIFICATION PROGRAM FOR MID-LEVEL ACADEMICS AT A GERMAN UNIVERSITY OF TECHNOLOGY

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Empowering teachers for facilitating modern engineering education is essential. Thus, universities put much effort in qualifying teachers in didactic training programs. Especially individualized programs have been positively evaluated in the Covid-19-year 2020 by participated teachers. However, participants missed (informal) networking opportunities. Two questions arise: How do participants perceive their qualification program in the coming years? And second, how can we design a program that balances the participants' thirst for an individual program compilation while establishing university-wide networking opportunities among teachers? This paper presents participants' perceptions on a qualification program at a German University of Technology for the years 2021 – 2022. Also, it presents key practices of a revised program. After four groups completed their program, data was gathered through online questionnaires and descriptive analyses (48 responses of 106 participants). Also, four semi-structured interviews were conducted and content analysis was used as interpretation method. Results show that this qualification program is positively perceived in terms of acceptance, learning, future teaching activities and program characteristics. Specifically, participants define their training group as trustful, but only a part of them feel to share responsibility for teaching. Their personal teaching networks consists mainly of staff from the same school within the faculty and other mid-level academics. Interestingly, they encourage to tackle teaching challenges within the wider university community. Thus, both individual pathways and informal, cross-disciplinary opportunities for dialogue should be possible in a program that is flexible in terms of time and topics. Hence, qualification programs should be designed to address the challenges of contemporary higher education as a teaching community rather than as individual.

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1 INTRODUCTION

Empowering teachers to enable modern pedagogy in engineering education is key in order to keep quality of teaching at a consistently high level while dealing with abrupt teaching transitions due to Covid-19 earlier (e.g. Sherman et al. 2023) or recently the enormous rise of artificial intelligence tools in teaching and learning (e.g. EUA 2023). Accordingly, associations and universities put much effort in qualifying teachers with didactic videos, podcasts, online or on-campus short formats, one-day workshops or complete training programs with varying approaches and workloads (e.g. E-teaching.org 2020, ECIU 2022, KI Campus 2023). Both, didactic qualification programs using cohort approaches according to Bulmann et al. (2018) and individual approaches have been positively evaluated as described by Bulmann and Bornhöft (2021). In the latter example that deals with the Covid-19-year 2020, participants found it more important to flexibly design their own program than go through a predetermined program in a cohort. However, they missed out on networking opportunities. Therefore, they recommended offering voluntary, primarily informal networking opportunities. Two main questions however remained and are pursued in this paper: First, how do participants perceive their flexible qualification program in the following years and how do participants describe their teaching networks. Second, how can we redesign the program so that the participants' thirst for individual program compilation and university-wide networking opportunities among teachers are balanced. This paper starts with describing the qualification program and the evaluation methodology. Results of participants' perceptions on the qualification program of a German University of Technology in the years 2021- 2022 are described. Based on these evaluation results and also taking reflections of didactic program experts into account, key practices of a revised program design are presented. This paper concludes on how to offer both an individual path as well as informal, cross-disciplinary options for dialogue in a didactic qualification program, striving for high quality, contemporary, transitioning engineering education.

2 METHODOLOGY

2.1 Implementing the Flexible Program

To ensure a high quality, contemporary education for mid-level academics, the executive committee of a German University of Technology initiated a flexible didactic qualification program, focusing on research assistants with teaching obligations. Attendance is obligatory for those funded by university budget. The program consists of 60-time hours over a maximum duration of two years. The aim is to enable participants to discuss didactic principles, apply methods and media to their teaching, develop their own teaching personality, present teaching-related products, and network across schools and faculties in terms of teaching. The program consists of an individual initial conversation (1 h), a variety of workshops (24 h), complementary elements (teaching project (21 h), peer visit (9 h), reflection (3 h)) and a final event for presenting the teaching project to the university public (2 h). Digital Teaching and Learning is a cross-cutting theme and reflects even more the adaptation of the training to Covid-19-disruptions in teaching and learning. Two main themes are offered, reflecting both the interest of previous participants and the identity and purpose of the university:

- “Higher Education and Engineering Pedagogy” (HE/EP) based on e.g. Berger et al. (2006) as well as
- “Engaging students in research with Research-Based Learning” (RBL) based on Healey (2005).

The broad area of HE/EP offers a wide range of didactic workshops in the catalog, while special RBL workshops have been offered continuously on two topics and additionally on varying topics. In the teaching project, participants innovate courses, analyze student learning or communicate about their teaching. In the peer visits, pairs of participants give each other feedback on their teaching in each other’s courses. In the reflection, participants review their teaching philosophy and practice. Every six months, a new group of participants begins and a previous group graduates from the program. Meanwhile, participants choose their own program path in regard to time and topics, based on their interests and needs for their current teaching practice and/or personal development. Flexibility, individualized pathways, and teaching practice based on a scientific foundation have been key features of the program since its inception. Four didactic experts guide the participants.

From the start of the program in 2019 to 2022, the program was constantly evaluated and iterated, based on the feedback of the participants and the reflection of the didactic experts. The program changes that were implemented foremost in summer 2021 include: (1) going back to on-campus workshops, (2) offering networking meetings in the reflection element, (3) shifting to the university learning management system, (4) suggesting to conduct peer visits with the teaching project partner, (5) recommending an optimal program duration of one year as well as (6) optimizing and digitalizing management processes to run the program.

The first group (G1) graduated in winter 2020/21, as described by Bulmann and Bornhöft (2021). From summer 2021 to winter 2022, 106 participants graduated in four groups (G2-G5). 55 participants were awarded with the certificate on the wide area HE/EP, while 51 participants received the special RBL certificate. 57 teaching projects have been carried out: 7 participants carried out their projects alone, 25 completed a project with a partner from the same school within the faculty, 10 with a partner from another school in the faculty and 15 even with a partner from different faculty.

2.2 Evaluating the Flexible Program and Deriving a Revised Program

We asked participants how they rated the qualification program after the first run and how they describe their teaching networks. We focused on the perceptions of four groups after they completed their programs: G2 (summer 2021), G3 (winter 2021/22), G4 (summer 2022), G5 (winter 2022/23). A mixed-method approach was applied: Data were collected from the four groups using self-administered online questionnaires and descriptive analyses (48 responses from 106 participants). In addition, four semi-structured interviews were conducted with participants of group 2 (summer 2021), of which two individuals completed the wide area HE/EP and two individuals completed the special area RBL. The interview guide focused on the overall evaluation of the program and the description of networks. The interviews were transcribed, coded, and interpreted using qualitative content analysis. Across the groups, the study was designed according to the first three levels of training program evaluation by Kirckpatrick and Kirckpatrick (2015): *Reaction* (R), *Learning* (L) and *Behavior* (B), while the latter refers to participants' future teaching intentions. Additionally, perceptions on teaching-related networks have been addressed: First, groups of persons that participants considered important in overcoming teaching challenges have been roughly identified. Second, personal networking maps with three levels of importance were used and interpreted according to Jenert (2021). And third, microcultures have been investigated according to the four types of microcultures by Roxa and Martensson (2015): *The Commons* with high trust and high shared responsibility ('We are in this together'), *The Club* with high trust and low shared responsibility ('We'll always support each other'), *The Market* with low trust and high shared responsibility ('I look after myself') and *The Square* with low trust and low shared responsibility ('Who are these people?'). Results on program evaluation (section 3.1) rely on questionnaires of four groups of graduates (i.e. G2 to G5), while results on networking (section 3.2) are presented based on interview data (of G2) and survey data (of G4, G5). The training program was then revised based on the evaluation results, reflections by didactic experts on running the training, emphasizing recent needs in regard to university strategies and contemporary engineering education.

3 RESULTS

3.1 Evaluation of the Flexible Program

Participants' Reaction, Learning, and Behavior Regarding the Program

Participants of all four groups (G2-G5) perceived the flexible qualification program as positive according to the questionnaire results (see Table 1).

Table 1 Participants' perception of a qualification program aggregated for four groups graduated in 2021 and 2022.

Level	#	Item	Ø	n
R	1	I find a structured didactic qualification as research assistant important.	1,4	48
	2	I find it personally valuable that I have participated in the program.	1,8	48
L	3	I can develop initial approaches for an aligned course.	1,5	48
	4	I can develop initial approaches for a research-based learning course.	1,6	23
	5	I can develop initial approaches for a digital course.	1,5	47
B	6	I am motivated to develop my own teaching continuously.	1,3	48
With three levels: Reaction (R), Learning (L), Behavior (B), answers on a 4-point scale with 1…totally agree to 4…totally disagree, Ø: arithmetic mean and n: number of responses from groups 2 to 5				

Participants' Perceptions on Individual Program Selection and Cohort Aspects within the Program

Participants rated the program positively in regard to the implementation of the four program characteristics: content flexibility (Ø=1.6, n=48), time flexibility (Ø=1.5, n=48), participants' needs (Ø=1.8, n=48), and teaching practice (Ø=1.8, n=48). In particular, participants find it more important to flexibly design their own program than go through a predetermined program in a cohort, i.e. 36 of 48 respondents voted for an individual design. So, the possibility to select workshops individually (groups 2-5: Ø=1.1, n=48) as well as to choose the focus of the complementary elements (reflection, peer visit and teaching project) (groups 2-5: Ø=1.5, n=48) was highly appreciated. In conclusion, participants appreciate the program's focus on their teaching needs and practice, and the opportunity to make their own decisions about their individual program pathways.

Participants' Perceptions of Program Support when it Comes to Solving Teaching Challenges

Participants experienced multidimensional challenges in Covid-19-times, especially related to organizing, designing, interacting, and assessing student learning in online teaching (despite group 5). Various program elements have been appraised as supportive to overcome these challenges (groups 2, 3): Impulses on digital teaching, such as didactic methods, techniques, tips, examples, the self-reflection element, peer visit element as well as exchange with other program participants, colleagues from other schools and didactic experts. Participants from group 4 (Ø=2.1, n=12) and group 5 (Ø=1.9, n=7) rated the support of the program as rather important.

3.2 Participants' Characterization of Personal Teaching Networks

Participants' Description of other Groups when it Comes to Solving Teaching Challenges (in Covid-19 Times)

Participants found it most important to overcome teaching challenges during Covid-19 times with colleagues of their own school and alone, followed by the university teaching community, didactic experts and colleagues of other schools (see Table 2).

Table 2: Participants perception of importance of others in overcoming teaching challenges

#	Item: "In COVID-19 times, how important is it to you to be able to master challenges with …?"	Ø	n
11	... colleagues of your own school?	1,2	48
12	... colleagues of other schools?	2,3	47
13	... didactic experts?	2,1	47
14	... the university teaching community?	1,9	47
15	... by myself?	1,4	47
Answers possible on a 4-point scale with 1…totally agree to 4…totally disagree, Ø: arithmetic mean and n: number of responses from groups 2 to 5			

Participants' Personal Networks for Teaching Exchange

The four interviewees (of G2) described their personal networks differently. Overall, they indicate that colleagues of the same school and other mid-level academics as well as professors, students, tutors, the program project partner and didactic experts are very important or important in their personal teaching network. Other groups, such as the IT department, the university's executive committee, industry colleagues, or previous colleagues are rated as a bit important (data not shown). This impression also correlates with the survey responses (of G4, G5) (see Table 3).

Table 3: Participants' perception of importance of other people for exchange on teaching

#	Item: "Who do you communicate with regarding your teaching, and how important are these people to you personally regarding your teaching?"	Ø	n
16	Colleagues from the qualification program	3,1	21

17	Colleagues from the same school	1,2	21
18	Colleagues from other schools/ faculties	2,8	21
19	Colleagues from other universities in your discipline (e.g. other universities; city/ national/ international)	3,4	20
20	Didactic experts of the Center of Teaching and Learning	2,4	21
21	Administrative staff (e.g. examination department, student administration office, IT department, library or others)	3,0	20
22	Colleagues on other academic levels (e.g. professors, senior researchers/ lecturers, tutors)	1,7	21
23	other persons (e.g. friends, family, industry/ business)	2,7	21
Answers were possible on a 4-point scale with 1…totally agree to 4…totally disagree, Ø: arithmetic mean and n: number of responses from groups 4 and 5			

Participants' description of Networks within their Schools and the Program regarding Trust and Shared Responsibility

The four interviewees (IA, IB, IC, ID) of group 2 explained in which way they share teaching obligations within their schools (professors/ head of school, senior researchers, colleagues of mid-level academics, tutors) and how they feel supported by didactic experts and the project partner. Microcultures within the schools and the program are described in the following:

First, the four interviewees positioned their teaching networks at their own school within three types of microcultures according Roxa and Martensson: 'The Commons', 'The Club' and 'The Market'. The fourth item 'The Square' was not chosen:

> *"Personally, I think is this, 'we are in this together.' But of course, it doesn't work like that* […] *So I would take either 'The Club' or 'The Market."* (IA, L410-118).
>
> *"So, in any case 'The Commons' […] always trust on* [person XY] […] *So much what sharing concerns."* (IB, L485-493)
>
> *"We are responsible together."* (IC, L230-234), *Rather 'The Commons' than 'The Market'*
>
> *"Between 'The Commons' and 'The Club'. The professor gives me a lot of trust and I give a lot of trust to the tutors, but the levels of responsibility are different. It's somewhat hierarchical."* (ID, L264-273)

Second, interviews (G2) and survey results of G4-5 outline that participants experienced the microculture within the program group predominantly within the three types: 'The Commons', 'The Club' and 'The Square', while 'The Market' was addressed only once. The digital format of the program was seen as hindering towards a feeling in the training group of 'We are in this together." (in G2 & G5). In particular, the working culture with the project partner (within or beyond the same school) was highlighted as being trustful and sharing ('The Commons'):

> *„I think that's where the digital teaching was a bit of a hindrance. That you just didn't have the feeling that 'we are in this together' or 'we will support each other'. But when I think about the project now. There I would even say that that was actually 'The Commons'. That we took this on together and supported it."* (IA, L422-427) ",*"The exchange with someone who is not in the school* [i.e. project partner], *who is already on the teaching side, but is not in his own school bubble, that really helped me. It substantially improved my teaching, simply because it was a completely different perspective. We understood each other well. It was a really good exchange."* (IA, L104-110)

“The Commons […] *the two participants, with whom I did the project* […] *they supported me relatively well.* […] *Otherwise, yes. I would say ‘What are you doing right now?’ somehow so ‘The Market’ or ‘The Club’.”* (IB, L499-517)

“More like ‘The Club’. We are a community of interest and want to make teaching better. But in the end, we do most of it on our own and in parallel and in independent groups. Even if a course goes over several schools, they are divided into several independent packages.” (IC, L237-240)

“Already so more ‘The Commons’. So, we have always acted as equals, especially in the workshops […]*. That things stay between us when it comes to a course, that you can tell each other things in confidence. We are in this together and go through it together and support each other in the things that are important to us.” (ID, L282-286). “Because it* [the program] *was digital, the exchange fell asleep. I only had exchanges with my project partner, otherwise we saw each other at the classroom events and we no longer had these discussions in breaks. That was difficult. That wasn't because of the program, but rather because of the* [Covid-19] *situation. The interpersonal level is very important to me, and it is precisely these discussions during breaks that lead to a more intensive exchange about things that are in teaching and things that are in everyday professional life. It's not just about what happens in teaching, but also what happens in research, and if all that falls away, there is less of a bond.”* (ID, L115-124)

These results outline the complexity of personal teaching networks. Both, while organically growing networks within the schools are of significant importance, trustful and sharing networks to project partners beyond the schools turned out to be essential for some participants. Both can be enforced within an on-campus program.

3.3 Our ten key practices of the revised qualification program

Our ten key practices of a balanced qualification program are presented here: Some practices (#4, 5, 8, 10) have been already introduced in summer 2021 (see section 2.2) and are feedbacked by some participants of G4 and G5 (see section 3.1., 3.2.). All practices are reflected in the recently published program (ZLL, 2023).

Practice 1: *Individual pathways*: Our training offers individual pathways along personal goals for newcomers, advanced and scholarly teachers. These are set in the initial talk by each participant. This aims that participants with all kind of interest, didactic backgrounds and teaching duties find personal value in the program.

Practice 2: *Balanced time flexibility*: Our training offers time flexibility for participants to design their program within the maximum program duration of two years. This aims that the program fits in the participants’ busy academic schedules. At the same time, three milestones (initial talk, project discussion, program reflection) are set within an optimal program duration of one year, envisaging to help structuring their pathways.

Practice 3: *Thematically open orientation*: Our training offers a wide-range of didactic topics like research-based learning, challenge-based learning and Artificial Intelligence tools in teaching and learning. The aim is to establish alternating specific areas and to initiate sub-groups sharing interest and responsibility in certain topics.

Practice 4: *Networking among groups of participants*: Our training offers various networking options, especially the first workshop and the network meetings. This is to subdivide the start-group into participants that share the same interest, teaching level or timing to implement the teaching project. It intends to build trust and reflect on shared teaching responsibility from the beginning.

Practice 5: *Acting in teaching practice with a partner from any school*: Our program offers to conduct the complementary elements (33 h) with a partner participant committed to in the first network meeting. The aim is, that participants develop their teaching competencies on a higher level, to build a partnership with high trust and high shared responsibility, to pool resources and for sure, to foster student learning.

Practice 6: *Support by professors/ school heads:* Our program welcomes professors to take part, among others, in the second milestone meeting where project teams meet the didactic expert to discuss their ideas. The intention is to understand each professor's teaching intentions, to jointly encourage participants, to reveal network opportunities and to guarantee a sustainable implementation of this teaching project.

Practice 7: *Supervision by didactic experts:* Our program offers each participant individual supervision in at least the three milestone meetings. Each supervisor is a didactic allrounder with special expertise and is responsible for all participants from two faculties. The aim is to build a trustful cooperation, offer didactic consultation and support participants in making progress in their own program pathway.

Practice 8: *Program delivery on campus*: Our program is offered foremost as an on-campus training. This intends to support informal, trustful exchange on teaching, research, and personal matters. Some digital elements (few workshops or milestone meetings) are offered online to suit better the time scheduling of all parties.

Practice 9: *Celebrating participants' achievements*: Our program offers a closing event within a university-wide summer fiesta. The Vice-President of Academic Affairs awards the program certificates. Participants present their teaching projects in a poster fair, and the most inspiring teaching ideas are awarded by the audience. This creates acknowledgement in a more informal get-together and communicates teaching innovations to all kind of university members.

Practice 10: *Robust program structure and processes*: Our program offers a robust and impactful general structure that is supported by optimized and digitally mapped processes. On the one hand, that helps offering that extent of individual pathways. On the other hand, it enables being active when facing abrupt challenges like digital transition due to Covid-19 or artificial intelligence tools in teaching and learning.

4 CONCLUSION

This paper outlines a didactic qualification program that is positively evaluated by participants over the last few years. It also sheds some light into participants' teaching networks which includes foremost colleagues of the same school, other mid-level academics, and the partner participant whom to share teaching responsibility and having a trustful partnership with. The ten key practices of the balanced program show on the one hand that each participant can be supported to grow as a teaching personality and to master direct challenges in courses. One the other hand, it paves the way for all participants to both rely on existing disciplinary networks and to build rich teaching networks with other participants, academia and administration staff which are then the backbone to (re)act as a university community on transitioning teaching challenges for engineering education that are around the corner. The results presented here are restricted due to methodological limitations. Future studies will focus on better understanding participants' networks and practices.

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What do we know about our first-year engineering students' backgrounds and experiences?

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Conference Key Areas: *Engineering Skills and Competences, Recruitment and Retention of Engineering Students*
Keywords: *Self-concept, prior knowledge, first-year*

ABSTRACT

Students entering university come from a wide variety of backgrounds and experiences, with differing levels of knowledge and exposure to professional skills. However, university entry criteria typically focus on academic ability in particular subject areas such as maths and physics, but little information is known about students' attitudes and abilities in a variety of other, important domains such as attitude towards engineering, communication skills and level of interaction with peers. Self-concept, a cognitive evaluation that an individual makes and customarily maintains with respect to themselves concerning their ability in a general or a specific area of knowledge, can be used to evaluate students' perception of their attitudes and abilities across these previously unmeasured domains for academics to better understand the composition of the first-year student cohort.

In this paper, results of surveying approximately 350 first-year engineering students' self-concept across several distinct domains are reported. Exploratory factor analysis was performed on the resulting data, yielding 8 composite factors comprising of a mix of the original domains. While students strongly associated academic ability with perceived skill in mathematics, there was a surprising pair of engineering factors that emerged – one that captures 'engineering affect' and one that captures students' perceived relationship between engineering and creativity. It was also found that self-concept in peer interaction and communication skills were lowest out of the 8 identified factors. The results will be used to develop activities and programs to suit students' needs, particularly in terms of improving peer interaction and communication skills.

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1 INTRODUCTION

Traditional entry requirements for engineering degrees focus on academic achievement in high school and the prior attainment of specialised knowledge in areas such as mathematics and the physical sciences. These requirements are often listed in terms of overall minimum percentile results or aggregate subject scores and the requirement that a certain amount of discipline specific units have been completed. Some degree programs also utilise entrance exams to ensure that students pursuing a given degree have mastered foundational concepts required for that program (Basavaraj et al. 2021). What these entry requirements do not reveal, however, is an understanding of the diverse backgrounds, experiences, and skill sets of engineering students. In an environment that is placing an increasing focus on the development of professional skills such as communication and problem-solving skills in engineering students (Nair et al. 2009), it is crucial to capture an understanding of students' perception of their level of these skills when they commence their degree and have mechanisms in place to track their development over time. Furthermore, there is a lack of vision of commencing students' attitudes towards learning, their sense of overall academic ability and concept of engineering. Note that these attitudes are distinct from the foundational discipline knowledge assessed through traditional entry mechanisms yet are crucial to understand, particularly in introductory engineering courses that are key to retention in engineering.

Self-concept, a psychological construct that refers to an individual's overall perception and evaluation of themselves, is a vital tool for assessing students' perceptions of their attitudes and abilities across these previously unmeasured domains (Gable 1986; Shavelson et al. 1976). A comprehensive understanding of students' self-concept can help educators better support their learning and development throughout their engineering education. To this end, this paper outlines the authors' approach to measure first-year students' self-concept across a number of important domains such as academic ability, communication skills and engineering self-concept. By undertaking this study, the authors sought to identify patterns and trends in students' self-concept that could inform the development of targeted activities and programs and cater to the diversity of student experience and self-concept, promoting a more inclusive and effective approach to their engineering education.

This study was conducted at the University of Melbourne, a leading university in Australia, where students complete a 3-year undergraduate Bachelor of Science degree followed by a specialist 2-year Engineering Masters degree, commonly referred to as a '3+2 model'. Participants of the study were sourced from a first-year general engineering course within the Bachelor of Science, which serves as a gateway to further engineering study in later years. Student experience and skill development in the course is vital for retention in engineering as students do not need to choose their major until the second year of their degree. Given a poor experience in the course, students may choose to drop out of Engineering and pursue another science major such as Physics, Chemistry or Computer Science. Additionally, with such a generalist first year, students come from a wide range of backgrounds and experiences, which has implications for ensuring equity within student project-teams. A mix of international and local students enrol in the course which further adds to the diversity of the first-year cohort.

This paper will introduce the notion and importance of assessing student self-concept and describe the development of the survey instrument. The results of conducting the survey on 350 commencing first-year engineering students will be presented and analysed. The paper will conclude with a discussion highlighting the key features of the analysis and what implications these might have on the development of student learning activities into the future.

2 METHODOLOGY

Self-concept is defined as a “cognitive evaluation that an individual makes and customarily maintains with respect to themselves concerning their ability in a general or a specific area of knowledge” (Gable 1986; Shavelson, Hubner, and Stanton 1976). It is a hypothetical construct, and has been identified as a contributing component in expectancy models of motivation, which are based on the notion that individuals will choose, and persist in doing, a task if they have a reasonable expectation for success (Pintrich and Schunk 1996). It has also been observed that academic self-concept has motivational properties such that changes in academic self-concept will lead to changes in subsequent academic achievement (Marsh and Yeung 1997).

Multiple instruments for assessing self-concept have been developed over the years that can be used with individuals from childhood through to late adulthood and have varying levels of psychometric soundness, the strength of their theoretical base, and utility in a variety of research and practice situations (Byrne 1996). The Self-Description Questionnaire III (SDQIII) (Marsh and O'Neill 1984) was originally developed for assessing self-concept in high-school students and has proven strong validity and reliability characteristics (Wylie 1989; Marsh and Shavelson 1985; Marsh 1990). The SDQIII defines 13 factors (e.g. mathematics, verbal, academic, relations with peers, physical appearance) to measure self-concept that are assessed using a 136-item questionnaire. It is not tied to a specific domain, unlike some other self-concept instruments, and as such was deemed to be an appropriate basis for developing an instrument to assess the self-concept of first-year engineering students at The University of Melbourne.

In order to assess students’ self-concept, the SDQIII was adapted for first-year engineering students in the following way:

- Five of the factors were adapted directly from the SDQIII: Mathematics (M), Academic (A), Creativity / Problem Solving (Pr), General Self-concept (G) and Honesty (H);
- A factor pertaining to Engineering (E) was created by modifying several of the SDQIII ‘Mathematics’ items to relate to engineering;
- A factor on Communication Skills (C) was created by modifying SDQIII items representing the ‘Verbal’ factor to more broadly cover communication skills, involving both written and verbal communication which are both essential for engineering students;

- A factor on Peer Relationships and Interactions (Pe) was created by adapting items from the SDQIII 'Relations with Same Sex Peers' factor, as teamwork plays an important part in first-year and subsequent engineering courses.

Ten survey items were taken or adapted from the SDQIII for each of these eight factors that were deemed most appropriate for understanding self-concept with respect to first-year engineering students. All up, there were a total of eighty items on the survey instrument and these were placed on the survey as statements in a pattern similar to that of the SDQIII – every eighth item belonged to the same subscale and items were randomly distributed by direction (positive or negative). This structure ensured that the items on the subscales were psychometrically distinct yet had strong internal consistency. A survey form was generated that asked students to rate how accurately each statement (item) described themselves and were provided with a seven-point scale ranging from "very inaccurate" to "very accurate" to perform this rating. It was decided to provide seven choices to help strengthen the reliability of the instrument and allow greater distinctions between responses (Gable 1986).

3 RESULTS

The self-concept survey instrument was administered to commencing Bachelor of Science students during scheduled class time. Students were given approximately 15 minutes to individually complete the paper-based questionnaire under exam-like conditions. All survey data were collected anonymously and students could elect to not participate in the survey by not submitting their survey to the facilitators. Overall, 350 students took part in the survey, with 294 students returning surveys to be included in the analysis, which were scanned and processed by a machine-reading program. Of these 294 surveys, 286 contained complete results and these were used as the basis of the analysis. The five most accurate and five least accurate statements, measured by the means of the item responses, are given in Table 1.

Table 1. Survey items with the strongest responses

Most accurate statements	**Mean**	**Std. Dev**
14. I am comfortable talking to other students	5.56	1.30
20. I find engineering concepts interesting and challenging	5.53	1.18
27. I enjoy working out new ways of solving problems	5.37	1.24
56. I am a very honest person	5.34	1.30
32. I nearly always tell the truth	5.33	1.37
Least accurate statements	**Mean**	**Std. Dev**
4. I have never been excited about engineering	2.21	1.26
24. Being honest is not particularly important to me	2.28	1.45
22. I don't get along very well with other students	2.3	1.24
9. I have hesitated to take courses that involve mathematics	2.42	1.59
69. In school I had more trouble learning to read than most other students	2.51	1.63

From these results it is noted that, overall, students have a strong interest in engineering concepts and enjoy solving problems in new ways. This is perhaps not surprising as the university typically attracts high-achieving students. Furthermore, Q20, Q27 and Q4 were amongst the survey items with the lowest standard deviations, indicating a level of uniformity in this sentiment. It is interesting to note that questions relating to Honesty and Peer Interaction also figure prominently in the strongest responses, potentially indicating a student body that appears to have a strong sense of integrity and personability.

Based on the instrument's original eight factors, average response values (normalised to 100%) for each could be determined across all respondents, noting that items on the survey instrument that had a negative direction were inverted on the scale. Mathematics, Engineering, and Honesty rated highest (71%, 70% and 72% respectively), while Communication Skills, Peer Relationships and Interactions, and Problem Solving rated lowest on average (67%, 66% and 66% respectively).

Overall, a composite total self-concept rating, out of 7, could be obtained via averaging results for all items for each student and then taking the average over all students. This revealed that:

- 43.9% of students rated themselves having strongly positive overall self-concept (greater than or equal to 5)
- 55.0% of students rated themselves having overall neutral self-concept (between 3 and 5)
- 1.1% of students rated themselves having negative overall self-concept (less than or equal to 3)

The original eight factors were selected to assess self-concept over dimensions deemed important for first-year engineering students. However, students were not explicitly told what these factors were, and thus further analysis was performed to indicate if survey items had similarity in patterns of responses by students and whether they mirrored the underlying factors. *Exploratory factor analysis* was used as a statistical technique to determine how particular items could be grouped together to define new, constructed *subscales* (Fabrigar et al. 1999). This was an iterative process, in that several analyses were needed to be run, each with different constraints, and then the results evaluated for interpretability. A more detailed discussion of the procedures available and the decision making process involved can be found in standard texts (Gorsuch 1983). All statistical analyses were performed using IBM's SPSS software package, version 28.

The matrix of simple correlations among the survey items contained a reasonable number of values in the range 0.3 to 0.7 with significance (2-tailed) less than 0.001, indicating the likelihood that the data set would likely factor well. To formally assess this, the Kaiser–Meyer–Olin (KMO) measure of sampling adequacy, which compares observed correlation coefficients with partial correlation coefficients, was calculated as 0.86. Kaiser (1974) recommends a minimum barely acceptable KMO value of 0.5, values between 0.7-0.8 as acceptable, and values above 0.9 as superb.

Factors were extracted using the *principal components analysis* method. A scree plot of eigenvalues and observation of the amount of variance explained by each one indicated between 7-8 strong factors. There was a clear break observed in the scree plot between the eighth and ninth eigenvalues, indicating a sensible choice of eight factors to extract. Structure was explored by extracting the eight factors using varimax (orthogonal) rotation and studying the pattern and magnitude of the loading (degree of association) of each survey item on each factor. The eight extracted factors explained 51.70% of the variance in the data set. The high degree of relatedness of the items within each factor permit the scores of these items to be combined into a single *subscale score*, shown in *Table 1*. The subscale names chosen in this table are indicative of the items that formed the factor.

Table 1 : Identified subscales and corresponding item numbers

Subscale	**Items**	**Instrument Factors**								**Average self-concept**
		M	**A**	**G**	**E**	**Pe**	**Pr**	**C**	**H**	
1. Mathematics / Academic	33, 49, 17, 25, 41, 50, 9, 34, 57, 66, 26, 65, 74, 73, 1	10	5	-	-	-	-	-	-	71%
2. General Self-concept	79, 7, 23, 31, 39, 63, 15, 47, 71, 55, 80	-	-	10	-	-	-	-	1	71%
3. Engineering Affect	60, 76, 36, 52, 4, 67, 35, 22, 54, 3	-	-	-	5	2	3	-	-	73%
4. Peer Interaction	62, 30, 70, 78, 46, 61, 14, 38, 51	-	-	-	-	7	1	1	-	66%
5. Communication Skills	77, 21, 37, 13, 69, 45, 5, 29, 53, 16	-	-	-	-	-	-	9	1	67%
6. Honesty	56, 24, 32, 64, 72, 48, 40	-	-	-	-	-	-	-	8	72%
7. Academic Sentiment	18, 2, 10, 42, 58, 43	-	5	-	-	-	1	-	-	70%
8. Engineering Creativity	68, 44, 27, 28, 20, 11	-	-	-	4	-	2	-	-	71%

Items with loadings of below 0.369 on any factor were not considered to load on it. Five items, with loadings between 0.292 and 0.369 (Q75, Q19, Q12, Q59, Q6) had no strong association with any factor and were not included in the subscale calculations. Three of these were from the original Creativity / Problem Solving scale and interestingly related specifically to creativity, indicating that students did not consider this factor independently in its own right. On the identified subscales, Mathematics / Academic, Engineering Affect and Honesty rated highest, while Communication Skills and Peer Interaction rated lowest on average.

4 DISCUSSION

Several interesting features were revealed when analysing the new subscales generated by the analysis. Of particular interest were subscales 1,3, 7 and 8 as these subscales showed interesting combinations of question groups and/or relationships between them.

Subscale 1 (Mathematics / Academic) comprised all of the mathematics questions plus several academic questions related to students' perceptions of their skill, for example "I learn quickly in most academic subjects". Both the academic and mathematics questions in this subscale were negatively aligned (positive questions have negative components and vice versa) which implies that negative perceptions of academic skill are aligned with negative perceptions of mathematics. This might reveal a relationship between perceived ability in mathematics and academic confidence and suggests benefits in building stronger confidence in mathematics in first-year students.

Subscales 3 (Engineering Affect) and 8 (Engineering Creativity) could be considered similar as they both contain a mix of engineering and problem-solving questions. Subscale 3 appears to measure an apprehension towards engineering indicated by the fact that it contains only negatively phrased questions, e.g. "Engineering Intimidates me" and "I'm not much good at problem solving", which are negatively aligned. Subscale 3 also contains two peer related questions that are also negatively aligned. This suggested the subscale was measuring a form of engineering affect.

Conversely, subscale 8 appears to measure engineering creativity and confidence in ability as indicated by a combination of skills-based problem-solving questions and engineering questions such as "I am quite good at dealing with engineering concepts". These questions are positively worded questions and are positively aligned. Unsurprisingly, both subscales strongly link problem-solving with engineering self-concept and thus improving problem solving confidence in first-year students could be key to reducing engineering apprehension and improving retention. Tracking problem-solving ability could also be a relatively straightforward method of tracking engineering self-concept.

Finally, subscale 7 (Academic Sentiment) appears to measure positive sentiment towards academic ability. The questions in this section are positively aligned and are mostly academic questions with one question relating to problem solving. These questions all relate to a students' sentiment or attitude towards academic subjects, e.g. "I like most academic subjects" or "I hate studying for many academic subjects". It is interesting to note that academic sentiment is separated from perceived academic ability, which is captured along with mathematics in subscale 1. Furthermore, academic sentiment is not aligned with self-concept in engineering, which is contrary to similar work involving engineering Masters students (Buskes 2019) who have likely had time to develop such an alignment. In future, it will be insightful to measure academic sentiment at the end of semester to see if it becomes more aligned with engineering self-concept.

Communication Skills and Peer Interaction had the lowest self-concept, with an average of 66-67%. This is likely due to the first-year cohort not yet having many opportunities to develop skills in these areas (potentially amplified through the effects of COVID-19 at high-school) and emphasises the need for more targeted development of these skills in the first-year cohort.

5 SUMMARY

In order to discover more about students' backgrounds and experiences, approximately 350 first-year engineering students were surveyed to assess their self-concept across eight distinct domains. It was revealed that students had lower self-concept in the factors of Communication Skills, Peer Interactions, and Problem Solving than in Mathematics, Engineering Affect and Honesty. Further analysis found that students strongly associated academic ability with perceived skill in mathematics and identified a pair of composite factors relating to engineering – one that captures affect towards engineering (Engineering Affect) and one that captures students' perceived relationship between engineering and problem solving (Engineering Creativity). The implementation of such a survey has permitted building a more complete picture of student self-concept, the results of which will be used to develop activities and programs to suit students' needs, particularly in terms of improving peer interaction and communication skills.

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Returning to on-campus activities for first-year engineering skills development - a comparative study

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Conference Key Areas: *Engineering Skills and Competences. Curriculum Development*
Keywords: *Skills development, first-year, project-based, on-campus*

ABSTRACT

Prior work by the authors on student skills development detailed the implementation of a suite of skills modules in a first-year engineering course. These modules were instrumental components in supporting the course's project-based framework that offered flexibility of choice and timing in a low-risk setting. It was found that, while receiving overall favourable student feedback, most students only completed the minimum requirements and largely chose technical modules according to the relevance to their project topic.

Due to the cessation of on-campus teaching activities caused by the COVID-19 pandemic, these modules were delivered wholly online. With the lifting of restrictions the following year, the modules were made available with several distinctions: (a) the option of completing wholly online or a mix of online and on-campus activities; and (b) a change to a graded assessment scheme to encourage students to put more effort into their completion.

An evaluation performed on the modules revealed that online-only modules were attended at a rate comparable to on-campus activities. The distribution of module completions over the semester was influenced by module availability, students' time management and module alignment with their project. A higher concentration of module completions occurring closer to deadlines indicated that students were more time pressed and completed the modules just in time. A change to the grading scheme did not appear to affect the take up rates of the modules but did result in better quality of work. Students still elected to complete modules aligned with their project, consistent with previous trends.

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1 INTRODUCTION

As a result of emerging from the COVID-19 pandemic, many universities that saw transitions from face-to-face to online learning during the peak of the pandemic are now having to transition back to traditional, on-campus delivery modes. During this transition, universities have adopted many different models of simultaneously supporting both online and on-campus students (Almendingen et al. 2021; Hur 2022). Hybrid styles of delivery, such as those combining online and on-campus students in design studio environments, often used in engineering, have raised issues of learner equity and access, cohort building, and negative staff and student perceptions (Thompson et al. 2021). ‘Split cohort’, or ‘dual delivery’, where online and on-campus students are treated as separate cohorts within a course and have distinct teaching streams (and possibly assessment tasks), can mitigate some of these issues, however there are still negative perceptions of such an approach, in terms of lack of face-to-face interaction with instructors and lack of support for online students (Kember, Trimble, and Fan 2022; Glazier and Harris 2021). These models typically assume that students able to attend on-campus activities must necessarily attend them, while online students are only able to attend activities in an online capacity. What is unclear, however, is what students’ preferences are when given the opportunity to *choose* between attending on-campus or online activities and whether this affects patterns of attendance, completion rates, scheduling, engagement and academic performance compared to when offered only as wholly online activities.

This paper describes how a suite of skills modules, initially introduced as online-only activities in a first-year engineering course during the peak of the COVID-19 pandemic, were adapted for a return to campus, permitting students the option to complete wholly online or as a combination of online and on-campus activities. These modules covered both technical (related to the specific design project) and general (i.e. professional) skills. Differences in patterns of behaviour between online and on-campus students across these two categories were investigated. Comparisons in student completion rates and timeliness to the wholly online mode of the skills modules that was implemented the prior year are also presented and discussed.

2 BACKGROUND

Prior work by the authors on student skills development detailed the implementation of a suite of skills modules in a first-year engineering course, Engineering Modelling and Design, at the University of Melbourne (Buskes and Chan 2022). These modules were instrumental components in supporting the course’s project-based framework, where students work on a semester-long project such as programming an autonomous robot, designing, building and testing a speaker, or simulating and mitigating the effects of a coastal flooding event. The suite consisted of four *general* skills modules – Teamwork, Report Writing, Video Production and Prototyping, designed to develop the professional skills deemed necessary for completing each project and six *technical* skills modules, developed to cover a range of discipline skills in engineering that closely aligned with the projects, namely Basic MATLAB/Simulink, Simulink Stateflow Robot Control, Circuit Theory and Analysis, Arduino, CAD & 3D Printing and QGIS. As part of the course assessment, students were required to complete at least one General skills module and at least one Technical skills module to qualify for 10% of the course mark.

The three general skills modules - Report Writing, Video Production and Prototyping were offered as self-paced, online modules developed in H5P, comprising guided activities that built towards the submission of a piece of assessment.

The six technical modules and the general Teamwork module were each originally designed as self-enrolled on-campus workshop-based sessions, where a demonstrator would facilitate a series of activities derived from the intended learning objective(s) of the particular module. During the 1.5hr facilitated workshop sessions, students would first progress through a set of guided activities and then be required to individually complete a set of specific tasks in order to be certified as having completed the module. In Semester 2 of 2021, when the skills modules were first introduced, these workshops were conducted wholly online due to COVID-19 restrictions and a pass mark was automatically awarded if a student attended the workshop and attempted the tasks, without consideration if all tasks were successfully completed.

3 CHANGES TO WORKSHOP-BASED SKILLS MODULES

With the transition back to face-to-face learning in Semester 2 of 2022, more than 90% of the students in the course reported being able to attend classes on campus. While the three general skills modules, Report Writing, Video Production and Prototyping, continued to be offered as self-paced, online modules in H5P, the workshop-based skills modules, namely the six technical modules and the general Teamwork module, had to be adapted to accommodate both online and on-campus students in the cohort. The implementation of such a hybrid delivery model provided students with flexibility in completing the workshop-based modules – the choice to either complete the modules entirely online (online preparation and online workshop session) or opt for a combination of online (online preparation) and on-campus workshop session as shown in Table 1. While the online mode of delivery was only available for those students who were unable to attend campus, both options were available to students who were able to attend campus.

Across the 12-week semester, an average of one out of four workshops were delivered online, distributed in a way that each skills module included at least one online workshop to accommodate the online students. QGIS remained the only skills module with wholly online workshops in line with the coastal flooding project which was offered as a simulation-based, online-only project.

Table 1. Delivery modes of skills modules (indicated by ‘X’)

		Mode of Delivery		
Module Type	Module	Self-paced Online	Workshop-based	
			Workshop Preparation (Online)	Workshop Session (Online / On-campus)
General	Teamwork	N/A	X	X
	Report Writing	X	N/A	N/A
	Video Production	X	N/A	N/A
	Prototyping	X	N/A	N/A
Technical	Basic MATLAB/Simulink	N/A	X	X
	Simulink Stateflow Robot Control	N/A	X	X
	Circuit Theory and Analysis	N/A	X	X
	Arduino	N/A	X	X
	CAD & 3D Printing	N/A	X	X
	QGIS	X	N/A	N/A

In the revised workshop structure, the workshop sessions maintained their 1.5hr duration, however the previous policy of an automatic pass mark for attendance and participation was replaced with a scaffolded assessment structure. Under the new structure, students were awarded a weighted mark for each of the multiple tasks they completed within the workshop session. This was implemented across both online and on-campus workshops as motivation for students to complete all the tasks to fulfil a particular skills module’s intended learning outcome(s).

4 EVALUATION AND DISCUSSION

In Semester 2 of 2022, the multiple delivery modes for the skills modules were offered to a hybrid cohort of 344 students, of which 25 were online-only students who were unable to attend any classes on campus. A comparative analysis was conducted to observe module completion trends between the wholly online cohort of 2021 versus the hybrid delivery cohort of 2022, where students had the option to attend the workshop sessions either on-campus or online.

4.1 Completion rate of skills modules

A comparison of the completion rates of the skills modules between 2021 (wholly online) and 2022 (hybrid) cohorts is shown in Table 2, where the 2022 hybrid cohort is further broken down into students who indicated they were not able to attend campus and those who indicated they were able to (but could chose not to).

Table 2. Completion rate of skills modules

Cohort	**% who completed at least one module**	
	General module	**Technical module**
Wholly online cohort in 2021	81.0%	86.7%
Hybrid cohort in 2022	88.9%	89.0%
- Students unable to attend campus	84.0%	56.0%
- Students able to attend campus	90.3%	91.5%

There was a slightly higher overall completion rate of both types of module in 2022 compared to 2021, however, when examining the breakdown of the 2022 data, it was observed that the completion rate for the Technical modules among students unable to attend campus was significantly lower at 56%. This contrasts to the on-campus students who achieved a much higher completion rate of 91.5%.

This discrepancy could be attributed to several factors. Firstly, on-campus students were familiar with the learning spaces hosting the on-campus workshop sessions and could conveniently attend the Technical module workshops after one of their other classes. Additionally, on-campus students had a broader range of workshop session times to choose from due to expected demand and thus had more options and flexibility in scheduling their workshop sessions.

In contrast, online students were perhaps disadvantaged by the limited number of online workshops offered during the semester, with only one online workshop session available for most technical modules. Motivation also likely played a role in the lower completion rate among online students. Unlike on-campus students, online students lacked the opportunity for face-to-face interaction with peers. As a result, they may have missed out on an element of peer encouragement and motivation, which can often be influential in completing workshop assessments.

The overall cohort completion rate for the Technical module of over 86% remained largely consistent from 2021 to 2022. This suggests that the introduction of task-based assessment components into the Technical workshop sessions did not affect the completion rate. In fact, informal discussions with students and demonstrators revealed that students were more motivated to complete all the tasks in the workshop, indicating that the assessment tasks served their purpose in facilitating student learning and ensuring that all learning objectives were fulfilled.

Further analysis of the 2022 cohort's completion of different combinations of the general and technical skills modules unveiled that a majority of students, comprising 85% of the cohort, completed only the minimum requirement (of one General and one Technical module) to achieve the skills module mark - a similar trend to the 2021 cohort. However, there was a slight increase of 1.5% in the number of students who completed more than the minimum requirement in 2022 compared to the previous year. The majority of students focused on meeting the minimum requirements, suggesting that the cohort generally aimed to fulfil only the necessary criteria to obtain the skills module mark. While some students demonstrated an inclination to go beyond the minimum, the overall completion pattern remained consistent with the previous year's cohort.

4.2 Uptake of skills modules workshop sessions

An evaluation of weekly workshop session subscriptions revealed that among the on-campus students, approximately 80% completed their workshop-based skills modules in the on-campus workshops, while the remaining 20% completed them online. Figure 1 shows the average percentage of subscriptions to on-campus and online skills modules workshops in 2022, computed from the ratio of the number of attendees to the workshop capacity limit. Based on the orange and blue bar-pairs in Figure 1, the average subscription rates between the on-campus and online workshops were surprisingly comparable, with a few exceptions - the Arduino module recorded zero subscriptions to the online workshop and the QGIS modules were exclusively offered online.

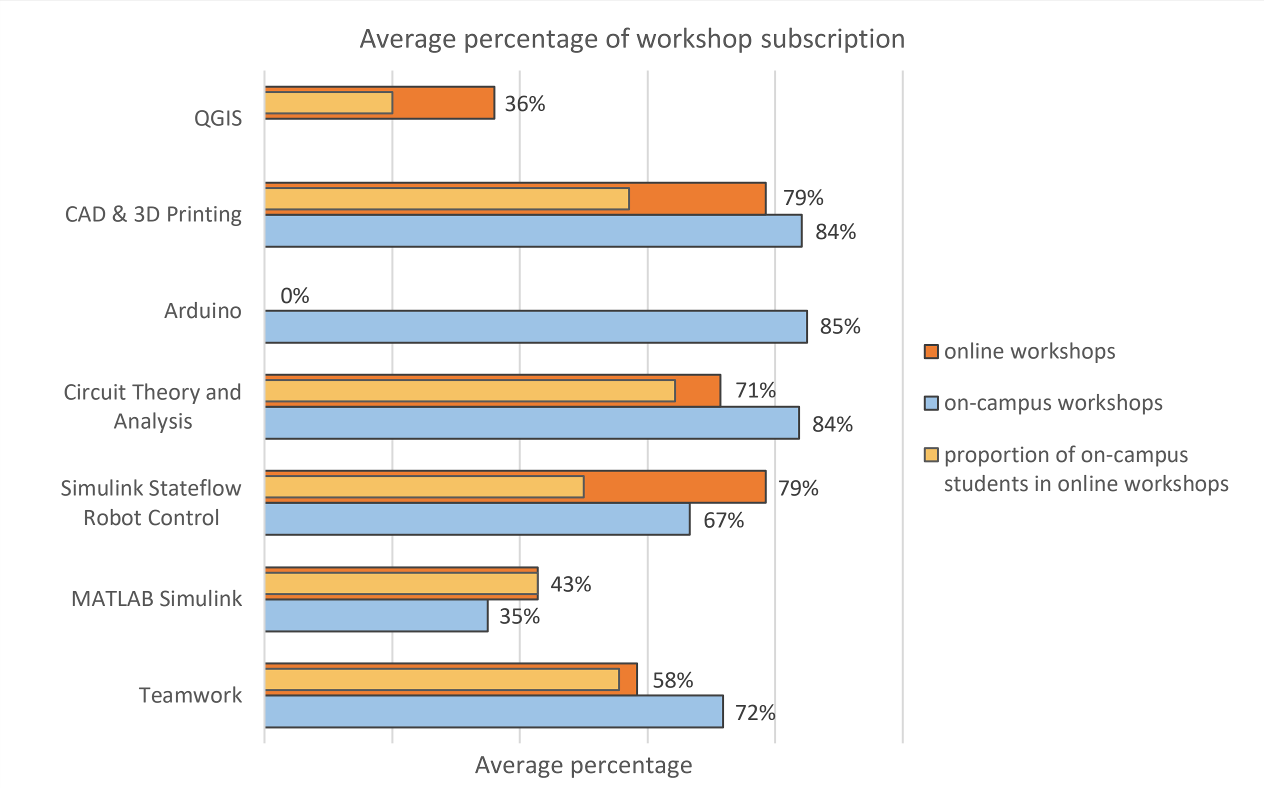

Fig. 1. Average percentage of workshop subscription in 2022

Within the online technical workshops, on average approximately 70% of attendees were on-campus students who chose to complete their modules online, represented by the yellow bars within the orange in Figure 1. It is worth noting that two outliers were not included in the observation: (1) 100% of the MATLAB/Simulink online workshop attendees were from the on-campus cohort, while (2) the online Arduino workshop had zero attendees, indicating a clear preference for on-campus attendance for this specific module. Significant on-campus student subscription to certain online workshops such as those involving Simulink and CAD, suggests that students were not opposed to attending online sessions for modules that had heavier emphasis on computer-based activities. On the other hand, students preferred the on-campus workshop for the Arduino module, which entailed programming hardware as opposed to simulation.

The online general Teamwork module subscription was dominated by on-campus students at the rate of 95%, mainly because the last Teamwork workshop was offered online at the end of semester and students had no alternative if they wanted to complete the module as part of the General module requirement.

In terms of subscription rates, the MATLAB/Simulink module did not attract as high an interest as the other modules, partly because this module was offered towards the first half of semester to provide basic knowledge in Simulink. Students in the Autonomous Robot project stream likely found that there was no longer a need to attend this basic module past Week 3 once they were well underway in their project. The QGIS workshops, offered fully online, were also poorly subscribed due to the very specific nature of the module only associated with the Coastal Flooding project and the small number of students in that project stream.

4.3 Timeline of skills modules completion

The completion of technical skills modules largely aligned with the particular projects, reaffirming the observations from the 2021 cohort (Buskes and Chan 2022). There was no discernible trend for when students chose to complete the modules with workshop components (i.e. the Teamwork and the technical modules) as uptake was reasonably distributed over the semester weeks, depicted by the solid blue coloured columns in Figure 2.

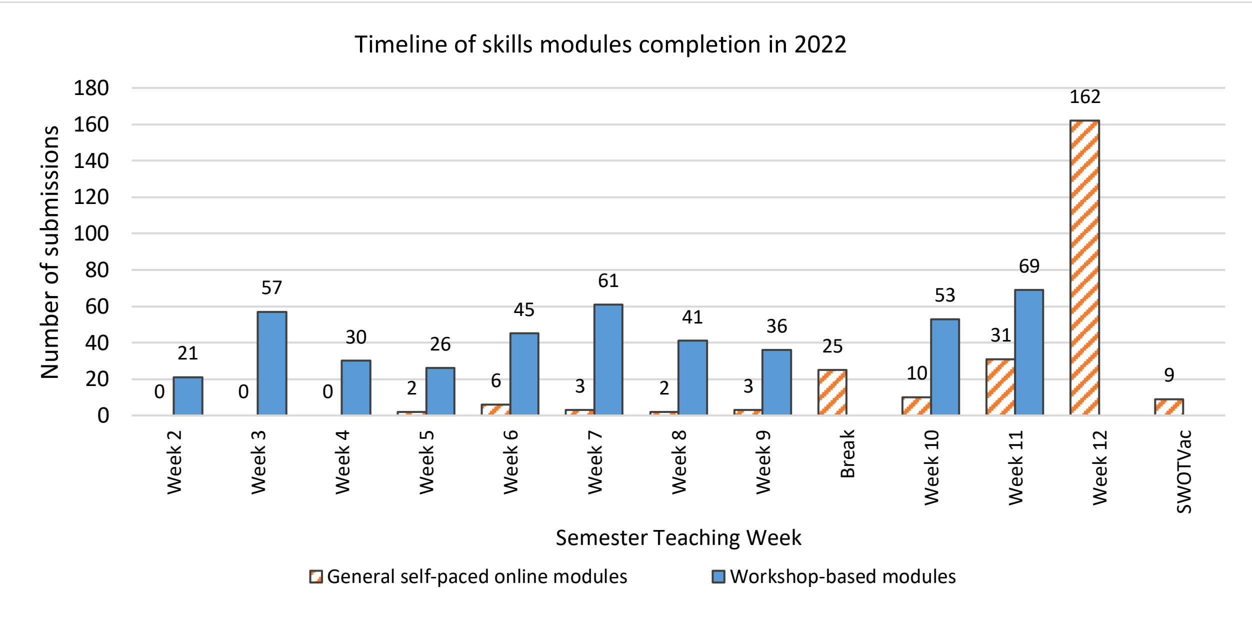

Fig. 2. Timeline of skills modules completion in 2022 (hybrid)

The general trend in 2022 was that higher module uptake occurred in weeks when more workshops were offered, suggesting that students tend to take up the technical modules at their convenience aligned with the availability of workshops. The peak in

Week 11 was likely the result of students rushing to fulfil the minimum skills module completion requirement before the workshops ceased.

There was a notable lack of completion of the general online self-paced modules throughout the semester until around Week 11 the, as shown by the orange patterned columns in Figure 2. A sudden surge in submission numbers occurred in the final week of the 2022 semester, which was the deadline for the general skills modules. The observation suggests that students from the 2022 cohort tended to prioritise completing modules with a workshop component first, as there are limitations to workshop offerings and availability. As a result, online self-paced modules were left to the end of semester when students were likely pressed for time. In 2021, the spread across semester was broader and not as concentrated in Week 12, which could be attributed to the additional flexibility that students had with wholly online learning and that they had more available time to spare by not having to travel into the campus during lockdown conditions.

5 CONCLUSION

With a hybrid cohort in 2022, the high completion rate of the workshop-based skills modules among on-campus students contrasted with the low rate among online students, suggesting that self-motivated enrolment into workshops is more effective when there is campus interaction among students. This is encouraging for future offerings of the course, with all university degree programs moving back to fully on-campus cohorts over the next year. With two delivery modes of workshops offered, on-campus students were not opposed to the option of online workshops for modules that are mainly computer-based, but preferred to do them on-campus if there was a hardware element involved. It was encouraging that the introduction of an assessment component in the workshops provided motivation to complete all workshop tasks and did not deter students from attempting or completing the modules. From the outcomes of the study, two areas for future improvements were identified: (1) planning of workshop offerings in future should be reviewed to avoid having too many undersubscribed workshops; and (2) considering offering an incentive to encourage earlier completion of the self-paced online general modules to bridge the significant gap between the completion time of the general and technical modules across the semester.

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DESIGNING OF CURRICULA OF ENVIRONMENTAL ENGINEERING AND CONSTRUCTIONS ENGINEERING FOR SUSTAINABILITY

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ABSTRACT

The experience carried out at the University of Florence, Department of Civil and Environmental Engineering, in designing two new undergraduate curricula in "Environmental Engineering" and "Civil and Building Engineering for sustainability", is reported. The bachelor in Environmental Engineering aims to train engineers capable of working in the field of protection of environment, territory and natural resources. The bachelor in Civil and Building Engineering for sustainability aims to train engineers capable of working in the field of structures, infrastructures, and constructions in general, as well as management and safety of construction processes. The development of the two curricula was based preliminarily on a national and international survey of degree programs of the same type and with shared learning outcomes. Subsequently, labour market needs were identified starting from discussions with all stakeholders, students and professors included. Teaching methods and methods for assessing students' preparation have also been revised and the teaching plan of both curricula is characterized in the third year by the presence of multidisciplinary laboratories, focused on the most characterizing themes of each

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programme and the different disciplines with integrative and specific in-depth characteristics. Finally, a thorough design of the two courses contents has been initiated, based on the definition of the general educational objectives and the specific disciplines.

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1 INTRODUCTION

Climate change and environmental degradation are now globally perceived as the greatest threat to Europe and the world: national and supranational institutions are pursuing strategies for a resource-efficient economy to face the challenge of sustainability. In particular, the European Commission through the "European Green Deal" (Fetting 2020) marks the roadmap to make the EU economy sustainable and aims to achieve this goal by transforming climate related problems and environmental challenges (environmental sustainability, resilience, decarbonisation, etc.) into opportunities with economic growth that is decoupled from the use of resources, with no person and no place being neglected.

The strategic objective is to transform Europe into the first block of countries with zero climate impact by 2050 (IPCC 2022). In this context, it is therefore necessary to strengthen and expand professional skills in numerous areas typical of civil, building and environmental engineering. The policies for the so-called "ecological transition" and the European directives on the circular economy, which have a prevalent part in the Recovery Fund, in order to be implemented need adequate financial instruments, and, above all, qualified and trained personnel to address these challenges.

The establishment of new degree courses is therefore perfectly in line with the strategic development guidelines of the European Commission envisaged in the Next Generation EU Plan and with the Italian National Recovery and Resilience Plan, which identifies the "Green revolution and ecological transition" and the "Infrastructures for sustainable mobility" among the six structural thematic areas of intervention.

In this context, the Department of Civil and Environmental Engineering (DICEA - *Dipartimento di Ingegneria Civile e Ambientale*) of the University of Florence has found the reasons to propose, starting from the A.Y. 2023-2024, the activation of a new Degree Course in Environmental Engineering (*Ingegneria Ambientale* - IAL), in the degree class L-7 Civil and Environmental Engineering, focusing more on the specific contents of Environmental Engineering and a strong revision of the current three-year degree in Civil, Building and Environmental Engineering, developed on three curricula: civil, building and environment. This existing course was deeply modified, starting from the name, which from 2023/2024 will be changed into Civil and Building Engineering for Sustainability (*Ingegneria Civile e Edile per la sostenibil*ità - ICE), and including all its most fundamental aspects (e.g. learning outcomes, career opportunities, study programs, etc.) with the aim of effectively defining a brand new course of study.

In designing the newly established IAL study program and revising the existing one, reference was made to the needs for innovation and sustainability coming from the labour market and, at the same time, to the priorities and objectives to which the University of Florence inspires its strategy of qualification and sustainability of the educational offer.

The review of the educational offer as a whole also stems from the results of a survey carried out to analyse the placement of graduates in civil engineering, building engineering and environmental engineering in the labour market (AlmaLaurea 2023), as well as it emerges from the investigation preliminarily carried out at national level on the three-year degree courses in the degree class L-7 Civil and Environmental Engineering.

The new study program and the revision of the current one are consistent with what observed in the largest Italian universities as well as in prestigious foreign universities, such as Harvard University, Stanford University, University of Cambridge and ETH Zurich.
From a methodological point of view, the definition of the two programs is in line with the solicitations coming from the world of industry and professions (Duderstadt 2010; Eckert et al. 2019; Van der Vleuten et al. 2017), and with the results of the surveys conducted by prestigious engineering training schools which have begun to question on the challenges that fast societal change poses to engineering education (Graham 2018).
In particular, attention was paid to the period of great change in the training of engineers in order to respond adequately to the demands of society. The change includes engineering study programs with a more relevant social-education component and with a greater focus on skills. Greater flexibility for students in the composition of their curricula, greater attention to multidisciplinary learning, increased students' awareness of the impact of technologies on the socio-economic context, and greater attention to the acquisition of soft-skills, are also fostered.
A study by UCL (2018), in this regard, reveals the importance of associating "soft-skills" with the "hard-skills" typical of engineering education, to focus on "inclusion and diversity" through more inter and multi-disciplinary curricula, focusing on disciplines that concern the development of an engineering career, the acquisition of know-how skills through the development of real projects and the growth of the international dimension through experiences abroad.
Formally, whether it is a newly established program or the revision of an existing program, the first phase of planning concerns the definition of learning outcomes, i.e. the set of knowledge and skills that characterise the cultural and professional profile, to which the curriculum is aimed at. This is followed by the definition of the specific Didactic Regulation for the Degree Course, i.e. the set of rules that regulate the specializations or curricula of the study programme, according to the University teaching regulations, drawn up in compliance with the reference legislation.
The final phase concerns the definition of the specialisations or curricula in which the degree course is organized and the set of university and extra-university training activities specified in the teaching regulations of the degree course for the purpose of obtaining the relevant qualification.
In the following, the methods on which the design of the new degree course as well as the revision of the existing one are based, are briefly described. The description concerns the national and international point of view on the central role of engineering degree courses and of engineers in framing the society of knowledge. The engineering education able to support and promote the changing is also discussed. The results achieved are finally described.

2 METHODOLOGY

The labour market becomes the privileged reference in the definition of training courses. In fact, there are numerous studies that have as a final result the definition of the professions that society will need in the future (WEF 2020).
Among the professions identified as strategic for the future, some are certainly attributable to the field of engineering (NAE 2017).
Nevertheless, some difficulties for engineering training schools in meeting the needs of a rapidly evolving society that poses global challenges, such as environmental and economic sustainability, protection and safeguarding of health and the environment are recognized. In the context of such challenges, the role of the Engineer is to imagine, implement and manage the technical infrastructure for sustainable change

and therefore the training and qualification of the engineers of the future plays a central role for the construction of the knowledge society (Morell 2010; Apelian 2007).
Specifically, among the challenges, the following can be traced back to ICE and IAL degree courses: i) provide access to clean water; ii) restore and improve urban infrastructures; iii) assess life-cycle of materials and structures; iv) use innovative and recyclable materials; v) design Nearly Zero-Emission Building (NZEB); etc.
Thus arose the need to respond to the necessities expressed by society with knowledge, skills and attitudes developed by students during their training in engineering schools for modern professional figures of engineers who know how to support and promote sustainable change. In this context, the learning outcomes of the two degree courses have been defined with reference also to the recommendations reported by ASME (2023) on: a) development of higher standards of professional and communication skills; b) increased flexibility in the study programmes. The definition of the learning outcomes, however, concerns the characterization of the cultural and professional profile, i.e. the set of knowledge and skills each curriculum aims to provide. Once the professional profiles and learning outcomes have been defined, the construction of the didactic regulation of the degree course is required. Each teaching regulation determines: a) the denominations and educational objectives of the study courses, indicating the relative classes to which they belong; b) the general framework of the training activities to be included in the curricula; c) the credits assigned to each training activity and to each area, referring them to one or more scientific-disciplinary sectors as a whole; d) the characteristics of the final exam for obtaining the degree.
Every year the Italian *National University Council* (CUN 2022), with reference to the regulatory context and the ministerial indications for the quality assurance of the Degree Programmes, provides indications for an effective drafting of regulations and the elaboration of a valid and well-structured teaching offer. On the basis of the regulation that constitutes the general framework of the Degree Course, different curricula may be developed within the same Course.
Both degree courses have been divided into three curricula that represent different education paths, but are aimed at achieving the same training objectives. Each curriculum is aimed at directing the training of students towards one of the professional profiles identified and to acquire skills directly usable in the world of work.
Also, as required by Italian Ministerial Decree No. 133/2021, the teaching plan is characterised by high flexibility.
Besides all the aspects described above and the specific disciplines of engineering, the contents of the two degree course are defined to adequately respond to some of the Sustainable Development Goals defined by the United Nations in the 2030 Agenda, namely: SDG 9-Industry innovation and infrastructure; SDG 11-Sustainable cities and communities; SDG 13-Climate action. The SDGs in IAL are integrated with: SDG 6-Clean water and sanitation; SDG 14-Life below water; SDG 15-Life on land.

3 RESULTS

The Degree Course in *Civil and Building Engineering for sustainability* aims to train first-level engineers of the degree class L-7 Civil and Environmental Engineering that add to the solid traditional technical training, also the ability to contribute to the sustainable development of the territories and the communities within which engineering works fit, ensuring that technological applications are consistent with the needs of future generations.
Classes which refer to the contents of the most characterising disciplines of civil and building engineering, suitably organised, so as to train technicians with a highly multidisciplinary preparation, essential for responding to the needs expressed by the

labour market and by a multiplicity of stakeholders and higher academic education, with particular reference to the following areas:

a) design, construction and operation of buildings and structures taking into account the sustainability of exploitation of natural resources and the possibility of recycling or reusing materials and waste;
b) design of hydraulic and geotechnical civil works;
c) planning, management and maintenance of works, plants, infrastructures and urban and territorial systems, and of civil systems and installations for the environment and the territory, also for the purpose of prolonging the life cycle and sustainability of the impacts generated;
d) acquisition and management of geospatial data;
e) management and safety of construction processes.

Three professional profiles with multiple professional outlets have been identified:

- Technician of structures, infrastructures and civil works;
- Technician for buildings and building systems;
- Technician for the management and safety of construction processes.

The course is then structured in three curricula (Table 1.1, 1.2 and 1.3), aimed at covering the main application areas of civil and building engineering and at training students towards one of the professional profiles identified:

1. <u>*Structures and Infrastructures*</u>: aimed at training technicians capable of operating in the field of structures, infrastructures and civil structures, through the use of both traditional and innovative, eco-compatible, recycled systems and materials and the integration of technologies based on renewable energy and water reuse;
2. <u>*Building systems*</u>: aimed at training technicians capable of operating in the field of building systems, using traditional and innovative techniques and materials, in the context of sustainability, from both an energy and environmental point of view;
3. <u>*Construction safety management:*</u> aimed at training technicians who have knowledge and skills in the management and safety of construction processes, also with attention to the concept of social sustainability.

Table 1.1 First year Study Plan of Degree Course in Civil and Building Engineering for sustainability.

Year	1st Semester		2nd Semester	
	Teaching Course	ECTS	Teaching Course	ECTS
I	Mathematical Analysis I	9	Physics	9
	Geometry	6	Statistics	6
	Computer Science Laboratory	6		
	Chemistry/Materials Technology*			12
Structures and Infrastructures				
I	Design/Geomatics*			12
Building Systems/Construction Safety Management				
I	Design/Fundamentals of Building Design*			12

**The course is a joint course composed of two different integrated sectors.*

Table 1.2 Second year Study Plan of Degree Course in Civil and Building Engineering for sustainability.

Year	1st Semester		2nd Semester	
	Teaching Course	ECTS	Teaching Course	ECTS
II	Continuum Mechanics	6	Structural Mechanics	6
	Thermodynamics and Heat and Mass Transfer	9	Geotechnics	9
	Foreign language (English)			3
Structures and Infrastructures				
II	Mathematical Analysis II	9	Fluid Mechanics	9
	Applied Geology	6	Fundamentals of Building Design or** Hydraulic Infrastructures	6
Building Systems				
II	Mathematical Analysis II	6		
	Building Technology and Sustainability*			12
	Building Process Digitization Laboratory*			12
Construction Safety Management				
II	Mathematical Analysis II	6	Sustainable Water Resources and Waste Management*	9
	Building Process Digitization Laboratory*			12

**The course is a joint course composed of two different integrated sectors.*
***Mandatory elective course: students are requested to select only one between the two courses proposed.*

Table 1.3 Third year Study Plan of Degree Course in Civil and Building Engineering for sustainability.

Year	1st Semester		2nd Semester	
	Teaching Course	ECTS	Teaching Course	ECTS
III	Structural Design	9	Traineeship	3
	Structural Analysis	6	Final Exam	3
	Elective Courses			12
Structures and Infrastructures				
III			Transportation	9
	Sustainable Structures Design Laboratory or** Sustainable Infrastructures Design Laboratory			15
Building Systems				
III			Energy and Environmental Building Assessment	6
			Sustainable Water Resources Management*	6
	Sustainable Buildings Design Laboratory			12
Construction Safety Management				
III			Transportation	9
			Building Production and Safety	6
	Sustainable Construction Management Lab			12

**The course is a joint course composed of two different integrated sectors.*
***Mandatory elective course: students are requested to select only one between the two courses proposed.*

The Degree Course in *Environmental Engineering* aims to train first-level engineers capable of operating in the field of environment, territory and natural resource protection.
Classes referring to the contents of the most characteristic disciplines of environment and territory engineering are provided, suitably organised, so as to train technicians with a highly multidisciplinary preparation, indispensable for responding both to the needs expressed by the labour market and by a multiplicity of stakeholders, and to higher-level academic training, particularly in the following areas:

a) prevention, control and remediation of the negative impacts on the environment of the various human activities,
b) environmental impact assessment of structures, infrastructures, urban areas, production activities and services,
c) prevention, monitoring and rehabilitation of hydrogeological instability phenomena and slope instability, management of river basins and the coastal environment,
d) management of natural resources with a view to sustainable development,
e) technical-managerial coordination in the context of optimal integration of processes related to Health, Safety and the Environment.

Three professional profiles with multiple professional outlets have been identified:

- Technician of Health, Safety and Environment (HSE);
- Technician for the protection of natural resources and sustainable development;
- Technician for the assessment and mitigation of natural and anthropic risks.

The Course is structured in three curricula (Tables 2.1, 2.2 and 2.3), aimed at covering the main application areas of environmental engineering and at training students towards one of the professional profiles identified:

1) *Safety, health and environmental quality*: aimed at training technicians who have knowledge and skills to support and verifying the full and integrated implementation of processes related to health, safety and the environment with the aim of contributing to the overall efficiency of companies/organisations;
2) P*rocesses and technologies for sustainable development*: aimed at training technicians capable of technical support during the construction and operation of technological plants, whether private or public utility, for the supply of drinking water and the treatment of wastewater, solid and liquid waste and gaseous emissions;
3) *Monitoring of the territory and mitigation of natural and anthropic risks*: aimed at training technicians capable to collaborate in all activities related to the surveying, management and protection of territory and urban areas also in the context of climate change.

According to the provisions of the D.M. 270/2004, the two Courses are structured in 3 years during which students must acquire 180 credits.
The teachings of the first year are almost entirely in common among all curricula and between the two Degree Courses. The second and third year, on the other hand, provide for each Degree Course teachings in common and others specific for each curriculum. Both courses and curricula require the presence of at least 12 ECTS freely chosen by the student, the assessment of the knowledge of English language (level B2), an internship in the third year and a final exam of 3 credits. The internship is 3 ECTS with the exception of IAL-HSE which has an internship of 6 ECTS.
The study plan also includes the presence of multidisciplinary laboratories, all located in the third year, focused on the most characterizing topics of the Degree Course and teachings with a supplementary and specific in-depth nature.

Table 2.1 First year Study Plan of Degree Course in Environmental Engineering

Year	1st Semester		2nd Semester	
	Teaching Course	ECTS	Teaching Course	ECTS
I	Mathematical Analysis I	9	Physics	9
	Geometry	6	Statistics	6
	Computer Science Laboratory	6	Geomatics and GIS	9
	Chemistry/Environmental Chemistry*			12
	Foreign language (English)			3

**The course is a joint course composed of two different integrated sectors.*

Table 2.2 Second year Study Plan of Degree Course in Environmental Engineering

Year	1st Semester		2nd Semester	
	Teaching Course	ECTS	Teaching Course	ECTS
II	Mathematical Analysis II	6	Structures	9
	Continuum Mechanics	6	Fluid Mechanics	9
	Thermodynamics and Heat and Mass Transfer	9		
Safety, health and environmental quality				
II			Industrial Safety	6
			Soil Mechanics	6
Processes and technologies for sustainable development				
II	Energy Systems	6	Soil Mechanics	9
Monitoring of the territory and mitigation of natural and anthropic risks				
II	Applied Geology	6	Soil Mechanics	9

Table 2.3 Third year Study Plan of Degree Course in Environmental Engineering

Year	1st Semester		2nd Semester	
	Teaching Course	ECTS	Teaching Course	ECTS
III	Hydrology and Hydraulic Structures	9	Environmental and Sanitary Engineering	9
	Elective Courses	12	Final Exam	3
Safety, health and environmental quality				
III	Traineeship	6		
	Energy Systems / Electrical Engineering*			12
	Environmental Management Systems and Quality Management Laboratory or** Renewable Energy Laboratory			15
Processes and technologies for sustainable development				
III	Water Resources Sustainable Management Laboratory			12
	Planning and Analysis of Impact in Urban Environment Laboratory or** Renewable Energy Laboratory			15
Monitoring of the territory and mitigation of natural and anthropic risks				
III	Multi-risk Analysis Laboratory			15
	Natural And Anthropic Hazard Mitigation Laboratory			12

***Mandatory elective course: students are requested to select only one between the two courses proposed.*

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A GAME-BASED LEARNING APPROACH TO ENHANCE UNDERSTANDING OF INTERFACE DESIGN PRINCIPLES IN DESIGN EDUCATION

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***Conference Key Areas**: Innovative Teaching and Learning Methods, Curriculum Development*
***Keywords**: User Interface Design, Game-based Learning, Embodied Learning, Product Design, Universal Design*

ABSTRACT

The design of user interface is an important and challenging topic for student designers to understand and master. The eight principles of good User Interface (UI) design are often taught using primarily cognitive approaches, which can leave room for improvement in students' ability to apply the principles in a variety of contexts. Game-based learning tools are recognised to be beneficial in university classrooms across a variety of discipline areas and topics due to their capacity to increase engagement. This project presents a first prototype for an instructional tool that leverages constructionism and embodied learning to enhance students' understanding and application of these principles. This tool takes the form of a board game, thus encouraging peer learning. To test the prototype, three usability tests were carried out. Each user group was unique, the first being internal to the design team, the second having some prior exposure of the subject, and the third, having no prior experience at all. In each sessions, the participants were presented with a series of UI challenges, for which they were asked to construct suitable design solutions. Following the sessions, and where possible, the quality of these solutions were evaluated against a scoring system. This initial study suggests that instructional board games may be flexible enough to support learning outcomes at various stages of knowledge and skills acquisition among different learner groups.

1 INTRODUCTION

1.1 Background & Rationale

A User Interface (UI) is a device that yields the capacity for a user and a system to interact or collaborate. This device is most often a graphical user interface (GUI), but more and more, a UI can also take the form of a voice-controlled interface (a VCI) or a gesture-based interface (GBA). UI design is the process of designing these devices. There are eight principles of good User Interface design (Schneiderman, et al. 2016). These principles, along with a description and examples, are listed in Table 1. In this upcoming collaboration project between The Technical University of Denmark (KT.DTU) and Technological University Dublin (TU), we are designing a gamified framework to develop an integrated approach to teach the principles of good User Interface design. For our first design iteration, we have selected principles 1 & 2, Strive for Consistency and Seek Universal Usability, as our primary focus. With respect to principle 2, Seek Universal Usability, it can be challenging for early designers to ignore their own instincts, perceptions and intuitions whilst establishing product needs. Developing an objective or empathetic approach can assist in overcoming this challenge (Leonard and Rayport 1997).

Game-based learning tools can be beneficial in university classrooms, not least because of their capacity to increase engagement (Justo, et al. 2022). Indeed, this study also serves as an exemplar of how student engagement increases with such activities. Our proposed instructional game aims to leverage the advantages of embodied learning to enhance students' understanding and application of the eight principles of UI design. More precisely, it proposes to augment a constructionist-inspired game with multisensory interactive learning mechanics using mixed reality technologies.

1.2 Literature

Our proposed product concept draws on two education discourses; constructionism and multi-sensory learning.

Constructionism is a pedagogy where learning occurs as a process of constructing an intelligible entity (Griffin 2019) (Papert 1987). De-constructionism is a pedagogy that is inspired by and related to constructionism, however in this case, a backward-engineering technique is utilised for learning (Griffin 2019). Constructionism is a common approach for teaching User Interface design (Khoo 2011) and it is our intention to use it to underpin the gameplay of our intended product.

From birth and throughout human development, cognitive, motor and social abilities emerge together. They are connected and complementary and exert influence on one another in a variety of different ways and contexts (Thelen 1992) (Adolph and Joh 2007) (H. C. Leonard 2016). In several studies in the field of cognitive science, it has been shown that the brain weighs individual external sensory cues according to their relative precision, and constructs a reliability model for sensorimotor control (Limanowski and Friston 2020) (Körding and Wolpert 2004) (Ma, et al. 2006) (Bestmann, et al. 2008). Cognizant of this nature, multisensory learning encourages teaching methods that utilise diverse motor and sensory interactions (Davis and Francis 2023). An example of where this has been exploited in teaching is in a technique known as enrichment, where acquiring vocabulary for a foreign language can be enhanced by coupling physical gesturing with traditional verbal activities (Mayer, et al. 2015). Guided by the concept of 'walking in someone else's shoes', multi-sensory learning approaches will be used to inform the game mechanics of our intended product.

Table 1. The eight principles of user interface design

#	Principle	Description	Example(s)
1	Strive for Consistency	Employ consistent layouts colours and fonts throughout.	The location of the menu should be the same on every page.
2	Seek Universal Usability	Design for diverse user groups	Cater for Novice and Experienced, International, visual or dexterous impairments.
3	Offer informative feedback	For every action, there should be interface feedback	
4	Design Dialogue to Yield Closure	Design for events that involve several steps (a group of actions)	E-commerce websites move users from selecting products to the checkout, ending with a clear confirmation page that completes the transaction
5	Prevent Errors		Users should not have to retype an entire name-address form if they enter an invalid postcode.
6	Permit Easy Reversal of Actions	As much as possible, actions should be reversible	Press a back button to delete data from a data entry box
7	Keep Users in Control	Users should be able to achieve their desired results	
8	Reduce Short Term Memory Load		Avoid interfaces in which users must remember information from one display and then use that information on another display

2 METHODOLOGY

2.1 Framework

The overall aim of this project is to develop an instructional design tool that is both useful, attractive and either superior or complementary to the current state of the art. User Centred Design (UCD) is an established iterative process that can be employed to support product development. Here, UCD lends itself to secondary and generative research methods, which are useful for concept development. Further, UCD is also compatible with investigative and analysis-based research methods, which are useful for product testing at various stages of design development. Our method is informed by the UCD process and is illustrated in fig. 1. Stage 1 of our method serves to deliver a design concept and will be illustrated in section 3 of this paper. Stage 2 is concerned with usability testing and will be presented in section 4. Stage 3 addresses design iterations and involves cycling through stage 1 & 2, until the design has been refined.

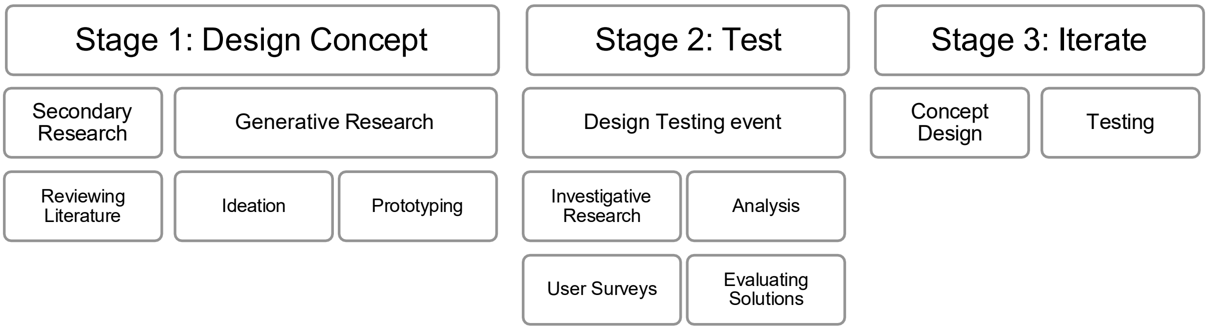

Fig. 1. Methods Diagram

3 CONCEPT DESIGN

3.1 Game Assets

A carbon tracker was selected as the subject for our game-based tool. There is no particular reason why. The tool would be just as effective had we chosen any other subject. In a brainstorm session, 7 unique features were identified that appeared to reasonably constitute a complete application (Table 2). For our initial product mock-up, and to speed up the design phase, we limited our focus to just three of these features, namely, Navigation, Calendar and Tracker.

Table 2. Features for the Carbon Tracker App concept, indicating

#	Feature	Variations	# UI Elements	Mock-up Ready for Review?
1	Navigation	1	13	Yes
2	Calendar	1	11	Yes
3	Tracker	1	13	Yes
4	Methods	2		
5	Moderators	1		
6	Options	3		
7	Metrics	2		

To facilitate the challenge we designed three distinct assets, a collection of diverse UI elements, a UI Design board, and, a set of UI Challenge cards. The UI elements are a collection of pre-designed template pieces that, like with a jigsaw, can be used to construct a complete picture for a user interface design. The UI Design Board is a poster style collaborative work tool that facilitates the organization of the UI elements. The UI challenge cards direct the goals of each round of the game. Examples of these challenges are as follows:

- Construct a suitable UI for a User who is visually impaired
- Construct a suitable UI for a User who is new to digital technology
- Construct a UI Design that conserves screen space
- Construct a UI design that minimises cognitive load
- Construct a UI Design that is consistent in its design composition
- Construct a UI that is inconsistent in its design composition

A printable version of the game is available for download on our github repository here The UI Game Board.

3.2 Game Rules

The instructions for the game were conceived as follows:

1. Populate The UI Board with the UI elements
   a. Separate the elements into two groups, Icons and Text.
   b. Separate the elements in each group by feature
   c. Organize the Icon elements by size
   d. Organise the Text elements by size and function
2. Populate the blank UI Interface with appropriate UI elements
3. Pull a challenge card
   a. Using elements from the UI Board, construct an appropriate corresponding UI design

3.3 Scoring

The initial mock-up addressed three features. For each feature there was, on average, 12 UI elements to choose from, culminating in a total of 36 pieces. With a view to establishing a method to evaluate the participant's designs, each element was categorised according to several criteria (Table 3). Using these criteria, the number of unique combinations that emerged was 22.

Table 3. UI element categories

#	Group	# Variations	Options
1	Type	2	Icon, Text
2	Size	3	Small, Medium, Large
3	Font	2	Sans, Sans serif
4	Contrast	3	Low, Medium, High
5	Interaction	3	Expand, Dropdown, Select

Subject to our current stage of development and where appropriate, each element was also given a score based on their suitable application for each challenge in the challenge card deck. Here, the assignment varied from poor to excellent across a 4 point Likert scale.

The scores for two challenges, to design a UI for (1) a user who is visually impaired and (2) to conserve space, are now complete. The main criteria for assigning these scores related to the elements size, font and contrast. For example, a UI element would have to exceed a minimum size threshold to score high on a challenge to design for a user who is visually impaired. Conversely, the same UI element may score low on a challenge to conserve screen space.

A process of developing scores for challenges that are concerned with design consistency and cognitive load are currently underway. As designing for consistency is a product of the position of and the similarity between elements, and cognitive load is impacted by levels of detail and variability, we will need to engineer a scoring matrix to evaluate these challenges reliably.

4 TESTING

4.1 Usability study

Table 4. Summary of Testing Sessions

#	Participants	Count	Participant Configuration	Date
1	Members from the Project Team	2	Individuals	15/04/23
2	Students from Y3 of the Product Design undergraduate programme at TU	6	Pairs	19/04/23
3	PhD scholars, Postdocs and faculty from the PROSYS research centre at DTU	17	Teams of 5-6	27/04/23

We conducted a usability study comprised of three sessions, a summary of which is provided in Table 4. Each of the sessions built on insights garnered from the one before. The first session was internal to our design Team where the participants were very familiar with the vision of the project. As such, we will exclude this session from further discussion. The process for session two and three is outlined below.

4.1.1 Session 2

1. A facilitator presents the 8 principles of User Interface Design
2. The concept and aims of the game are introduced.
3. Round 1, each team:
    a. Receives a randomly selected challenge card
    b. Constructs a corresponding UI design
    c. Presents their outputs and discusses the rationale with the rest of the group and tutors.
4. Round 2, each team:
    a. Receives the same challenge card – one for a user who is visually impaired
    b. Constructs a corresponding UI design
    c. Presents their proposals and the rationale for same
5. Each team fills out a feedback sheet, including observations made in the presentations.

4.1.2 Session 3

1. A speaker presents a talk on Cognitive Load Theory, Embodiment, and, this UI design Project
2. Game packs are distributed
3. Working as a group, each table:
    a. Organises the UI elements according to the UI Design board format
    b. Selects a challenge card from the challenge card deck
    c. Constructs a corresponding UI design
    d. Repeats, if time permits

3\. Each table collectively fills out a feedback sheet

For clarity, the key differences between session two and three are illustrated in Table 5.

Table 5. Variability between Testing session two and Testing session 3.

#	Variable	Level 1 Learners	Level 0 learners
1	Lecture / Talk (Primer)	The Principles of User Interface Design	Cognitive Load Theory & Embodiment
2	UI Design Board Activity	No	Yes
3	Present & discuss results	Yes	No

4.2 Investigative Research

A survey for the testing sessions was designed to establish the following:

- The base competency of the participants
- Which variables (e.g. activity, tool, instructor, peer) are perceived as having value for teaching
- Participant sentiment in relation to -
  - The suitability of the teaching approach
  - The pleasure of learning this way
- The quality of the instructional tools in relation to:
  - Ease of use
  - Perceived purpose
- The existence or otherwise of any unexpected use cases

5 RESULTS

It is important to bear in mind that the testing sessions were subject to high variability. Further, the level of subject exposure differed between the undergraduate students who participated in session two and the PhD scholars, postdocs and faculty who participated in session three. Therefore, and hereafter, we will distinguish the participants from session two and session three as level 1 learners and level 0 learners respectively, where level 1 denotes prior subject exposure consistent with an introduction and level 0 denotes no prior exposure at all.

Due to the limited extent of the scoring feature of the current prototype, we will also limit the quantitative analysis of the participant's designs to round 2 of session two. The main reason for doing so is that only the Level 1 learners integrated all of the available features into each of their solutions. Whilst the Level 0 learners did not produce designs that were substantial enough to evaluate, at the same time, the session facilitators were able to garner some insights through dialogue. For example, one Team who were challenged to design a UI for 'users new to technology' deliberately selected Text elements instead of Icons to increase familiarity. In another example, a different Team who were challenged to design a UI to 'reduce cognitive load' constructed a fuss free UI using large elements for a single feature.

5.1 Solution Evaluation

In round 2 of session two, three teams of two participants were challenged to design a UI for a user with a visual impairment. All three teams performed well and the solutions are illustrated in fig. 2. Scores for each design are set out in Table 6 whilst a short interpretation regarding the quality of each design is discussed forthwith.

Fig. 2. Testing session 2, Round 2, Results for the challenge to design a UI for a visually impaired user

Table 6. Scores for the challenge to design a UI for a visually impaired user

Element ref	Score	Team			Element ref	Score	Team			Element ref	Score	Team		
		1	2	3			1	2	3			1	2	3
f1	*1*				*t1*	*4*	**4**			*c1*	*1*			
f2	*1*		**1**		*t2*	*1*				*c2*	*4*	**4**		
f3	*4*				*t3*	*4*				*c3*	*1*			
f4	*4*				*t4*					*c4*	*1*			
f5	*1*				*t5*	*2*				*c5*	*2*		**2**	
f6	*2*			**2**	*t6*	*-*				*c6*	*4*	**4**	**4**	
f7	*4*			**4**	*t7*	*2*				*c7*				
f8	*1*				*t8*	*2*				*c8*	*2*			
f9	*1*				*t9*	*1*				*c9*	*1*			
f10	*1*				*t10*	*2*			**2**	*c10*	*1*			
f11	*2*				*t11*	*4*	**4**	**4**	**4**	*c11*	*4*	**4**		**4**
f12	*4*	**4**	**4**		*t12*	*4*	**4**							
f13	*-*													

Team 1 took an approach to provide users with the flexibility to work with minimal or maximal content at any given time using ‘show and hide’ functionality. Whilst the elements were a mix of icons and texts, the size, contrast and font options were a good choice for their intended user.

Team 2 took a creative approach and extended the UI design features using drop down functionality. Coupled with the medium sized calendar option, the image suggests that a design choice to conserve space may have been in operation.

Team 3 appear to have prioritised consistency, demonstrated in their commitment to using icons for all features in both designs. Only one of their designs includes an element for the calendar function. The sizing of this calendar block is more consistent with the medium sized icons, and is located accrodingly.

5.2 Participant Survey

A survey was designed to elicit qualitative responses from participants at our testing sessions. For the questions that correspond to 1, 2, 3, 4 and 5 in figure 4, participants were given the options Nothing, Something and A lot to choose from. For the questions that correspond to 6, 7 and 8 in figure 4, participants were given the options Not at all, Somewhat, Mostly and Completely. These options were converted to a numerical system (to 0, 2 and 4 in the first instance, and 0, 2, 4 & 6 in the second) for the purpose of graphing and comparing general sentiment across the two testing sessions.

In both events, participants (on average) scored the instructor and their peers higher than the activities themselves as a support for learning. The Level 1 Learners rated the teaching instruments, instructions, activity and 'point of the exercise' somewhat higher than the Level 0 Learners. Conversely, the Level 0 Learners rated the appropriateness and enjoyment of the learning method somewhat higher than the Level 1's did.

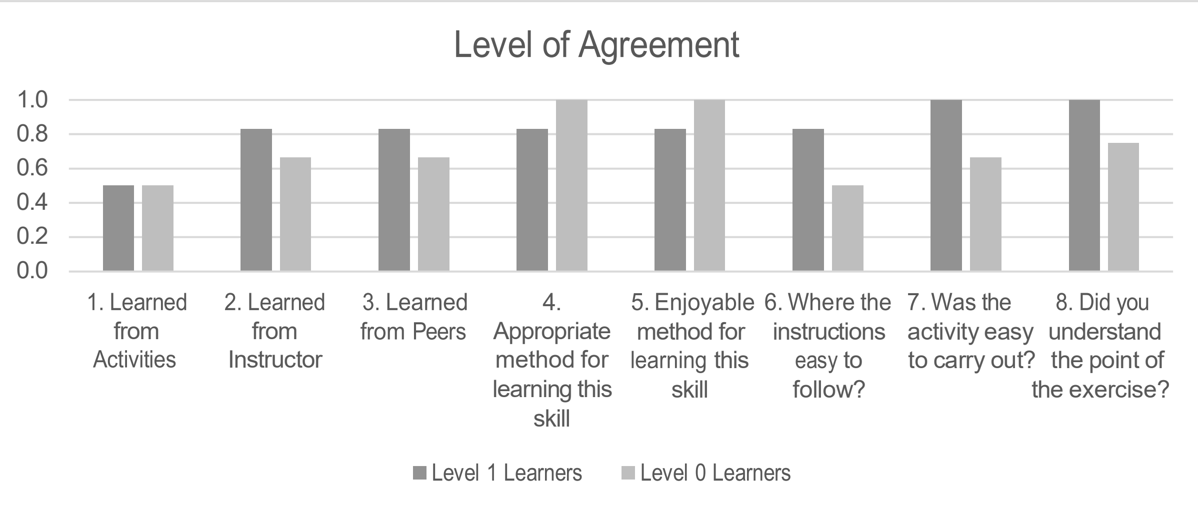

Fig. 4. Comparison of survey responses for user testing session

6 DISCUSSION & FUTURE WORK

Bearing in mind that we are discussing a handful of results across two early product testing sessions, still, there is a suggestion that these tools have different value propositions for learners at different levels of skill and knowledge acquisition.

As a teaching instrument, activities were valued less than the Instructor and Peers by both groups, indicating that learning was a social process. Further, the more experienced learners perceived the social process as being more valuable. These results are consistent with a recent case study that leveraged board games as instructional tools where the authors suggested that peer instruction may have more value among novice groups with some prior exposure (Carberry, et al. 2022).

In the next phase of this project, the team will look to explore the value of instructional board games as both an introductory tool for learners with no prior experience, and, as a revision tools for those with an elementary understanding.

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Using Padlet on math collaborative learning in an engineering course

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Keywords: collaborative learning, active methodologies, Padlet, mathematic

ABSTRACT

This paper describes a study, with the objective of evaluating the possibilities of knowledge construction through collaborative learning (CL) in the innovative Padlet environment. During the practical classes of a math curricular unit of an engineering course, activities and assessments were carried out using Padlet. Program themes are organized by columns as a wall. Each students group accesses a problem proposal using a QR-Code. In the first part of the class, the group must solve the problem correctly, using all the materials and technologies they deem necessary. In the second part, each group will correct another group's problem. The teacher provides the necessary support with the role of advisor in carrying out the proposed problems. Through the direct observation of the teacher during CL classes using Padlet, the experiences of the authors and the evaluation of the students in these contents, it was possible to collect information that allowed demonstrating that the students developed capacities and reached competences, some of them specific to professionals in the area of this course. Students' opinion gathered with a questionnaire will also be very important data to be presented regarding their interest in this collaborative activity. In conclusion, this paper will describe, analyse, and discuss the interest in using a CL environment for the development of knowledge and for student motivation in teaching/learning math for engineers. Students' perspectives will be observed regarding their motivation and interest, allowing teachers to expand the range of perspectives on the contents covered and enriching the necessary discussions for future activities development.

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1 INTRODUCTION

Facing the new society based on the creation, publication and sharing of information in a network, digital tools can and should be used as essential and complementary resources in the teaching and learning process. National and international research has pointed to collaborative learning (CL) as a facilitator in the teaching and learning process. CL is a teaching-learning methodology where students work together in groups or individually on a collective task. It could be a group activity where subjects undertake different parts of the task but contribute to a common goal, or it could be a shared task where students work together. Collaborative schools are generally successful in dealing with difficulties (students with and without disabilities must work together and support each other in building effective schools), are schools with lower dropout and repetition rates, and teachers seem to be more satisfied and committed to the work they develop [1–4].

Mathematical Analysis (MA) is usually taught in the first years of engineering courses. This curricular unit (CU) has a large number of failures and evasions due to the students' learning difficulties and the bases they bring from secondary school. It is up to the teacher to motivate his students, encouraging them to reflect and understand the proposed contents and to be aware of the importance of learning in their lives.

Padlet [5] is a collaborative platform, like a dynamic wall in a virtual panel format, where users can publish texts, photos, links, videos or any other content of interest. The Padlet also allows you to deepen your knowledge on the subjects addressed, record learning and reflections, stimulate curiosity, share with other users, that is, develop more active skills. Therefore, this tool is an important didactic resource [6, 7] that provides new pedagogical strategies, streamlining learning and allowing the teacher conditions to stimulate students' interest, which can be successfully used in the classroom. In addition, it ensures that the teacher is a facilitator of the teaching and learning process, while the student, the protagonist of this process, exercises his autonomy and creativity by translating his results into knowledge [8, 9]. Thus, the objective of this study is to discuss the potential of using Padlet as a CL environment, diversifying activities and enriching classes, capturing the active participation of students both in the classroom and outside of it, in addition to stimulating their critical thinking. How can the use of Padlet contribute to student learning? Can collaborative classes in virtual and controlled environments be useful for student success today? Are teachers, as tutors, capable of transmitting the mathematical knowledge and skills required of engineering students? These and other issues will be addressed and discussed throughout the experiments described in this paper.

2 METHODOLOGY

In the second semester of the academic year 2022/2023, in the CU of Mathematical Analysis of the Degree in Electrotechnical and Computer Engineering at the Polytechnic Institute of Coimbra, in laboratory practical classes, collaborative learning tasks were implemented using the Padlet. The classes were planned in such a way that the tasks were conceived with the intention of encouraging the active participation of the students, as well as developing skills intrinsic to the function of a researcher, assuming that they could be co-builders of their knowledge itself. Learning was focused on the acquisition of syllabus contents prescribed in the subject's syllabus, arousing interest in the contents to be explored.

3 EXPERIMENTS IN CLASSES

In the first classes, the students created the groups, registered in the Padlet and for each of the groups a column was allocated in the Padlet environment. In this column, the elements of the group were identified by their names and student numbers (see figure 1). Some experiments were also carried out in order to make the students feel comfortable using the Padlet.

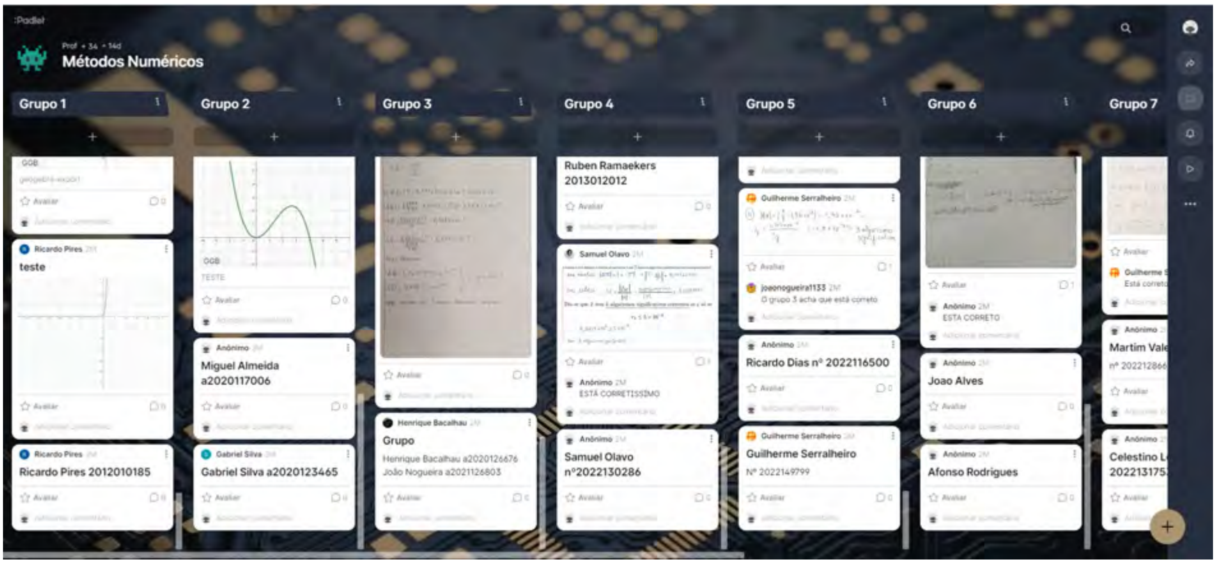

Figure 1: Example of Padlet at the beginning of laboratory classes.

In the following classes, the CU syllabus related to numerical methods were taught in these laboratory classes for 1h30m per week, where students have access to computers. In each practical class, a topic, among the existent 7, as shown in Table 1. Each task is previously planned by the teacher, following the objectives so that learning is achieved by the students. For example, in topic 1 on absolute and relative error, it is intended that students know how to calculate each of these errors and are able to have an idea of how the approximation should be so that the error has a given degree of precision. Thus, in this topic, the problem proposed to the students is based on the calculation of the absolute and relative error when approaching two values and the number of significant figures and decimal places obtained with this approximation. To access the proposed problem, the group must read the QR-code provided.

In the figure 2 it is possible to observe the posts of several groups on the topic "Graphical method for finding roots of nonlinear equations" of the third task (see Table 1). It can be observed that some of the groups solve the problem on paper and then photograph and upload the image, as in the case of group 3 and 5, others use digitizing tables, create a pdf and upload. Whenever possible, they use GeoGebra and/or other computer programs to graphically represent the functions, as can be seen in the images represented in groups 4, 6 and 7 (columns 3, 5 and 6 of figure 2 respectively).

Each practical class referring to a topic was divided into 3 parts, as shown in figure 3. Part 1, lasting 15 minutes, consisted of the individual resolution of an exercise on the topic learned in the previous class. Each exercise was quoted at 0.57% of the CU assessment mark. In part 2 of the class lasting 1 hour, students in groups of 2, independently research and learn the topic, with the guidance of the teacher.They discuss, in pairs and solve 1 or 2 random problems from a proposed list that they can access by reading the QR-code. The resolution is carried out with all the technologies they have available, such as the calculator, online applications such as WolframAlpha, Math Solver or GeoGebra and other applications that they have either on their computer or on their mobile phone. At this point they sometimes use digitizing tables, or paper and pen to register their resolution. At the end of solving the problem, they upload them to the Padlet in the column corresponding to their group.

Table 1: Topics, questions and objectives of tasks performed in laboratory classes.

Tasks	Details	
1^{st}	Topic	Absolut and Relative Error: Definition, Formula
	Questions	Calculate the absolute and relative error when approximating two values. How many significant figures and decimal places does this approximation have?
	Objective	To know the meaning of absolute and relative error and identify a certain degree of accuracy.
2^{nd}	Topic	Approximation by Differentials.
	Questions	Approximate the value of a function near a known value by differentials.
	Objective	To calculate the differential of a function and use differentials to approximate values for expressions.
3^{rd}	Topic	Graphical method for finding roots of nonlinear equations.
	Questions	Identify intervals that contain the roots of nonlinear equations through the graphical method and ensure the existence of a single root in an interval.
	Objective	To apply the graphical method and find intervals that contain only a single root of the equation.
4^{th}	Topic	Bisection Method: Definition, algorithm, and error.
	Questions	Approximate a root of a nonlinear equation using the bisection method with a given error.
	Objective	To know how to apply the procedure of the bisection method, identify its advantages and disadvantages, and calculate the error approximation.
5^{th}	Topic	Newton-Raphson Method: Definition, algorithm, and error.
	Questions	Approximate a root of a nonlinear equation using the Newton -Raphson method with a given error.
	Objective	To know how to apply the procedure of the Newton-Raphson method, identify its advantages and disadvantages, and calculate the error approximation.
6^{th}	Topic	Numerical integration: Trapezoidal Rule.
	Questions	Estimate the number of intervals in the approximation for a given error and then find the approximation by the trapezoidal rule.
	Objective	To identify when it is necessary to apply numerical integration, find the smallest number of intervals to obtain a given approximation and apply the trapezoidal rule.
7^{th}	Topic	Numerical integration: Simpson Rule.
	Questions	Estimate the number of intervals in the approximation for a given error and then find the approximation by the Simpson rule.
	Objective	To identify when it is necessary to apply numerical integration, find the smallest number of intervals to obtain a given approximation and apply the Simpson rule.

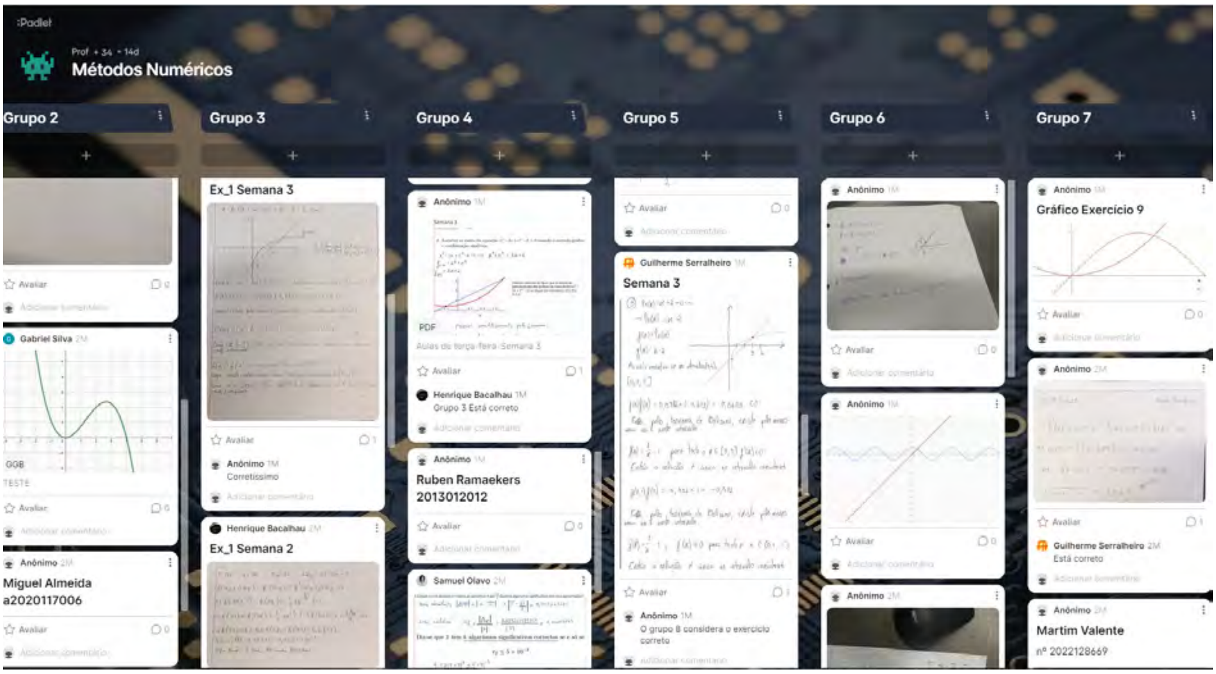

Figure 2: Example of Padle in the lesson of task 3.

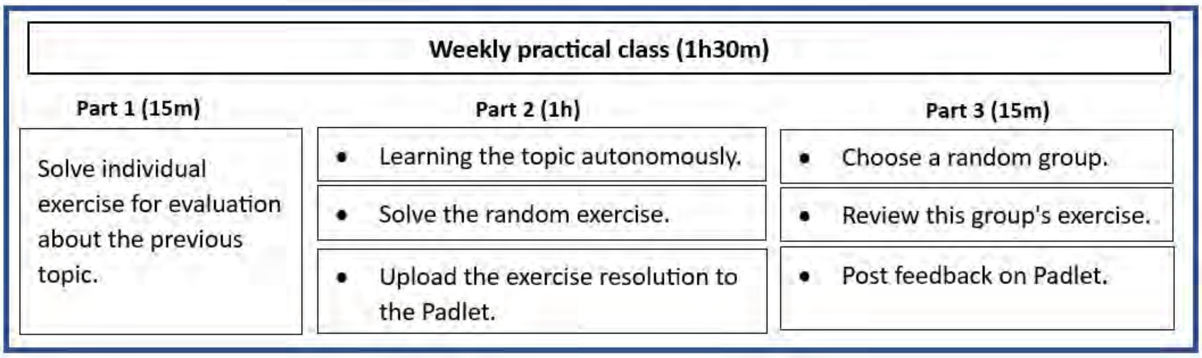

Figure 3: Flowchart of laboratory classes in each week.

Finally, in part 3 of the class lasting 15 minutes, each group chooses a partner group at random and corrects the problem posted on the Padlet, adding comments and new resolutions if necessary. In the figure 4, two feedbacks on the resolution of the problem on the topic are represented. On the left, the feedback from group 5 that corrected the problem of task 4 performed by group 3 and commented: "Group 5 considers the problem correct"; on the right, group 2 corrects the problem on task 1 performed by group 4 and comments: "Correct".

All proposed exercises and theirs corrections are available on Padlet during the semester. Students can and should refer to these resolutions while they prepare themselves for the following week written assessment exercise.

During laboratory classes (figure 3), the teacher participates as a mediator, facilitating the teaching-learning process and contributing to positive transformations in the development process of his students. He has the role of challenging, arousing curiosity and encouraging the use of his students' imagination through situations in which the student is challenged and manages to develop critical sense and logical reasoning. At the same time, he must guide the learning of each student so that at each completed stage, the student's improvement becomes continuous, and the construction of skills and competencies takes place.

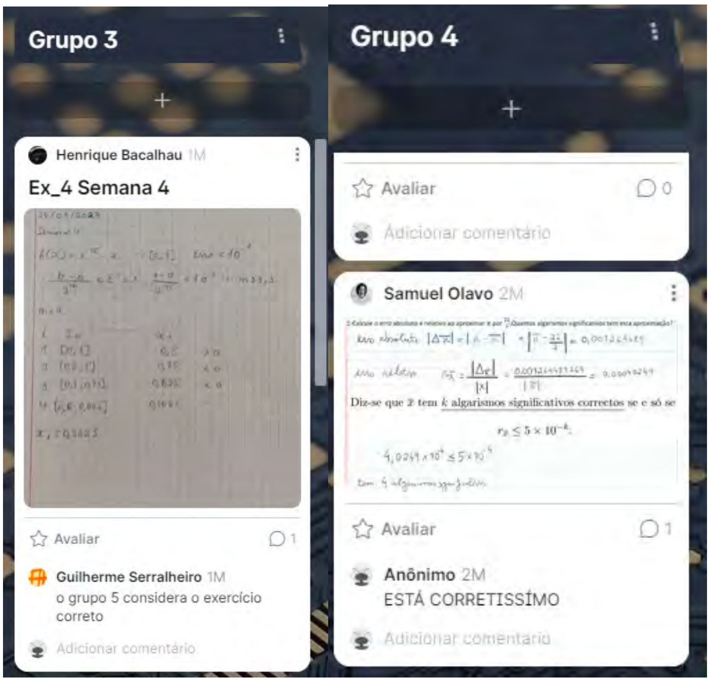

Figure 4: Exercise correction by peers group.

4 RESULTS & DISCUSSIONS

Of the 20 students who attended the laboratory classes, about 60% of the students had already carried out collaborative activities in the classroom, since many of these students had already attended this CU in the first semester. However, they had never used Padlet as a collaborative tool. In fact, only 1 student refers to having already used the Padlet, but not in a teaching-learning context.

From direct observation as an assessment tool [10], the teacher in the classroom observes the natural learning environment and collects "live" information, thus allowing momentary feedback and identifying perceptions by means of other assessment methods [11], according to the diagram shown in the figure 5.

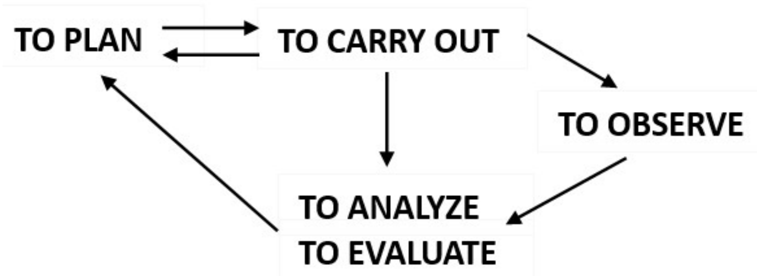

Figure 5: Classroom observation by each teacher (adapted from [12]).

During the several weeks of laboratory classes, the teacher registered the behavior of the students, both in terms of learning and in terms of collaborative activity in the group. Initially, the students were a little lost, as they did not know Padlet, nor were they used to attending math classes with access to different technologies. Regarding collaborative work, they were already used to experiences of this type carried out in the CU of the 1st semester, so cooperation and dialogue between peers was natural. As the weeks progressed, enthusiasm increased, carrying out tasks became easier, as students began to better understand how they should carry out autonomous study by the group, and the taste for the tasks grew. The peer assessment was the task that the students liked the most, because at that moment, in addition to learning being carried out, it is a way for the student to recognize the skills and competencies that he has acquired, in an autonomous way. As a teacher, it is a pleasure to observe the progress that students have obtained in mastering the contents and the joy they show, which can be observed in the evaluation of the proposed exercises at the beginning of each class.

Regarding the evaluation carried out weekly at the beginning of the laboratory classes, it was possible to verify that all students were able to acquire knowledge, although in some tasks 1 to 2 students did not have a positive grade. It should be noted that these cases of failure always involved different students. Figure 6 represents the scores, with a maximum of 10 values, obtained by students in task 1 (left) and 4 (right) carried out in week 2 and 5 respectively. From the analysis of these examples, it is verified that 89% of the students in task 1 and task 4 have a positive grade, only 11% of the students did not reach the intended results. However, 73% (task 1) and 55% (task 4) have grades equal to or greater than 8 out of 10, which demonstrates that the vast majority of students manage to acquire the skills and abilities necessary for their learning. In the remaining tasks the results are quite similar. There is always a group of students, quite small (about 2 students out of 20), who cannot reach the necessary knowledge, however we can conclude that the learning was effective and real.

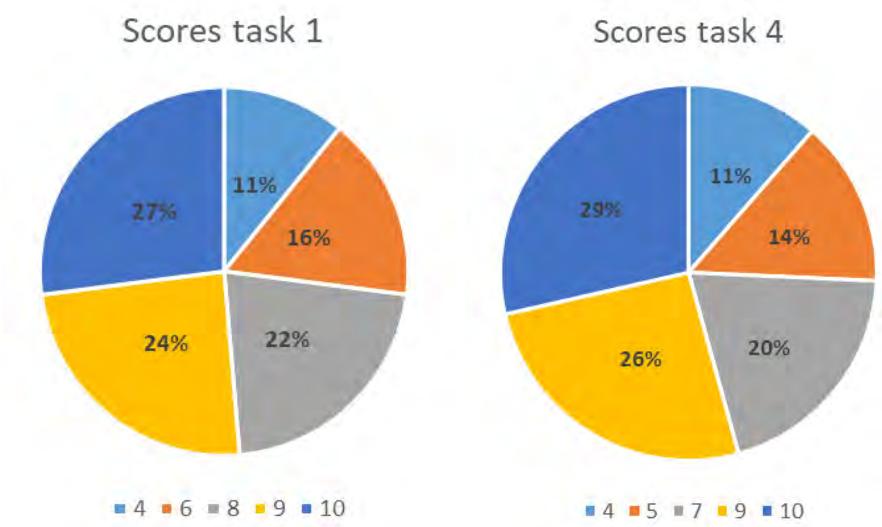

Figure 6: Student scores on task 1 (left) and 4 (right). Maximum value of the task 10 values.

5 CONCLUSIONS

The teaching of mathematics in an engineering school must capture the student's attention, be motivating, and allow students to acquire different skills and competencies that respond to the demands of the job market. Methodologies based on CL are an interesting example of how students can learn autonomously and acquired many transversal skills that will be useful to them as people and as professionals. The Padlet is a work tool that allows dynamic collaborative learning and can be used in a classroom environment in teaching-learning experiences.

In the study presented here, it was demonstrated that CL is effective learning as long as the student is involved in the constant search for his knowledge. For this reason, the presentation and monitoring of tasks in the classroom must always be accompanied and guided. The student learns to learn with his partner and together they obtain the necessary knowledge and associated skills. The teacher registers and guides, if necessary, but above all he is happy with the experience that he shows in the classroom. The use of Padlet in the CL of mathematics in an engineering course was an enriching, engaging experience that will be repeated in the next school year. The mural is a space for sharing the productions carried out by each group, where students have the resolutions of the proposed problem available at any time. The information available on this wall is extremely important for students in their preparation for the following week's assessment. This was one of the interesting aspects of Padlet recognized by the teacher and the students. Another no less important aspect was the possibility of using the Padlet to stimulate learning through the correction of problem performed by peers. By reviewing another group's problem, students are able to improve their skills and trust in their learning, fostering effective and meaningful learning, with consolidated knowledge.

The pedagogical use of the Padlet, as a technological tool, proved to be fundamental to implement CL and to experience the acquired knowledge in a more productive and relevant environment for the students' academic performance. The results show that it is possible to promote the development of students' mathematical skills and competencies, and to stimulate critical thinking, at the same time, using technology as an ally throughout the teaching-learning process.

6 ACKNOWLEDGMENTS

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Embedding sustainability in the engineering curriculum: Meeting the requirements of professional accreditation

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***Conference track**: Embedding Sustainability and Ethics in the Curriculum*

***Keywords**: Sustainability, Climate change, Curriculum, Accreditation*

Professional accreditation agencies are increasing requirements on sustainability in engineering education as a response to ethical obligations, industry needs and emerging academic best practice. In 2021, Engineers Ireland increased sustainability requirements in new accreditation criteria. This paper reports on a thematic analysis carried out by Engineers Ireland on the self-assessment and achievement of these new accreditation criteria on sustainability. The analysis was conducted on the self-assessment reports from a large Irish University, referred to as University A hereafter. The results indicate that, for the purpose of meeting accreditation requirements, University A has interpreted sustainability in their programmes as either meeting the UN Sustainability Goals (SDG’s) by mapping modules to the SDG's, or by aligning Programme Area (PA) 7 *Sustainability* of the Engineers Ireland accreditation criteria with the Engineers Ireland Programme Outcomes (PO's). The paper outlines the main themes and approaches identified across 17 engineering programmes and presents 2 case studies of how sustainability is embedded in engineering curricula in Ireland.

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1 INTRODUCTION

Engineers Ireland assess Engineering programmes in Higher Education Institutions (HEIs) in three main categories, Programme Outcomes (POs), Programme Areas (PAs) and Programme Management (PM). The assessment is outcome focussed, however professional accreditation agencies are increasing requirements on sustainability in engineering education as a response to ethical obligations, industry needs and emerging academic best practice (Beagon et al. 2021; DFHERIS 2021). In 2021, Engineers Ireland increased requirements on sustainability in their new programmatic accreditation criteria, specifically Programme Area 7 (PA7) *Sustainability,* becoming one of the first Washington Accord signatories to implement the new set of International Engineering Alliance (IEA) graduate attributes.

While there appears to be agreement on what the competences for addressing sustainability are (Wiek, Withycombe, and Redman 2011; Brundiers et al. 2021; Beagon et al. 2022) the ways and means they are adopted and embedded into engineering curricula is the subject of further investigation. Building on the work of ASTEP 2030 in identifying the ways that sustainability is embedded in engineering programmes (Kövesi et al. 2021; Beagon et al. 2022), this paper reports on a thematic analysis on the self-assessment and achievement of sustainability within the curricula of a large Irish Technological University, referred to as University A hereafter. The analysis was conducted on the self-assessment reports provided by University A seeking programmatic accreditation with Engineers Ireland. The paper outlines the main themes identified across 17 engineering programmes in 4 faculties at University A. Two case studies of exemplary programmes are also presented based on the outcome of the thematic analysis.

2 LITERATURE REVIEW

Accreditation is undertaken to ensure that education meets accepted standards and best practice and is the primary Quality Assurance (QA) process used to ensure the suitability of an educational programme as the entry route to a profession such as engineering (Augusti 2007). In Ireland, the professional accreditation of engineering programmes is undertaken by Engineers Ireland, the professional body for engineers. The Accreditation Board of Engineers Ireland is responsible for overseeing the accreditation process, making accreditation decisions, and recommending changes to the Accreditation Criteria.

Engineers Ireland's accreditation involves a periodic audit of engineering programmes by a visiting panel against the Accreditation Criteria. As the process is outcome-focused, the panel reviews a variety of evidence to ensure that graduates' attributes are consistent with the accreditation criteria. The criteria are aligned with the education standards for the professional titles of Chartered Engineer, Associate Engineer, and Engineering Technician (Conlon 2008).

The first Engineers Ireland accreditation was in 1982 (Engineers Ireland 2021) and there are currently more than 200 accredited programmes in Ireland. Extant literature demonstrates changes in accreditation criteria have an impact on engineering programme curricula. For example, ethics was introduced as a programme outcome more than 20 years ago. Subsequent research has demonstrated a less siloed and more holistic approach to ethics in engineering education (Homan 2020; Martin 2020). However, there are still different attitudes and cultural approaches taken to the technical & non-technical elements of the accreditation criteria in Irish Engineering Education (Martin 2020).

The Accreditation Criteria 2021 (Engineers Ireland 2021) is a comprehensive update on the 2014 version (Engineers Ireland 2014). A significant change in the 2021 criteria relates to a requirement to demonstrate sustainability in programme curricula. Specifically, graduates should have an understanding and appreciation of the environmental, social, and economic impacts of their judgments and to promote the principles and practices of sustainable development (Engineers Ireland 2021). Sustainability relates to the role of the engineer in society and professional conduct in terms of acting with honesty, integrity, and objectivity. Prior to the new criteria, where sustainability was addressed in engineering programmes in Ireland, it was often siloed within a single module (Homan 2020; Martin 2020).

Now, engineering education needs to be viewed in the context of the environment, to ensure that graduate engineers understands that they have responsibilities to society, the environment, and to their profession in general. It is more than a decade since Byrne and Fitzpatrick (2009) called for sustainability to become the context of engineering practice by:

" incorporating a sustainability informed ethos throughout engineering curricula" -p.1

by both professional institutions and educators. Furthermore, this should be accompanied by a commitment to the ethical usage of technology and data which is an important component of the increased use of data science, analytics, and emerging technologies (Engineers Ireland 2021). This is reflected in changing approaches to the accreditation of professional engineering programmes.

Sustainability means:

"reducing energy consumption and greenhouse emissions, to avoid depletion and degradation of natural resources, to ensure the needs of today's generations without jeopardising the needs of future generations" (Ghobakhloo et al. 2022) -p.12

However, including new technologies in the engineering programme curricula in isolation, is not sufficient. Complementary approaches such as sustainable thinking, circular intelligent products and upskilling and reskilling are also needed (Ghobakhloo et al. 2022).

At a macro policy level, it is widely recognised that the UN Sustainable Development Goals are important influences on engineering education (Kasinathan et al. 2022; Leng et al. 2022; Zeb et al. 2022). At a European level, two important strategic policy directions which are influencing the development of sustainability in engineering education are the Green and Digital transformations. The EU Green Deal (Kasinathan et al. 2022) demonstrates the necessity to transition to a more circular economy and increased reliance on sustainable resources, including energy (Xu et al. 2021). The EU digital agenda (European Commission 2015) will impact innovation and education for the next generation (Alexa, Pîslaru, and Avasilcăi 2022; Renda et al. 2022). Renda et al (2022) relates the UN SDGs to advances in engineering education in the realm of ethics and humanism. Looking to the future, engineering programmes should change their content after engagement with academic and industry (Cuckov et al. 2022).

In Ireland, research focusing on engineering accreditation (Homan 2020; Martin 2020; Chance et al. 2021; Byrne 2023; Doyle Kent 2021) demonstrates an opportunity to examine if changes made to the Engineers Ireland 2021 accreditation criteria has highlighted the sustainability activities embedded in the engineering curriculum.

3 METHODOLOGY

Seventeen programmes were assessed in the thematic analysis, these included Civil, Mechanical, Electrical, Electronic, Energy, Biomedical and Chemical Engineering programmes in University A. In Ireland, programmes are described by the National Framework of Qualifications (NFQ) as set out by Quality & Qualifications Ireland (QQI). The analysis included Higher Certificates (level 6), Ordinary Bachelor’s degrees (level 7), Honours Bachelor’s degrees (level 8) and Master’s degrees (level 9). The method used to identify themes was drawn from Braun & Clarke (Braun and Clarke 2006), who recommend conducting thematic analysis in 6 steps, which are outlined in Table 1.

Table 1. Braun & Clarke (2006) method for thematic analysis

	Step	Action	Output
1	Become familiar with the data	Read and re-read the submission documents	Preliminary ideas about codes
2	Generate initial codes	Organise data in a meaningful way	Coding of each document separately
3	Search for themes	Examine codes to see if some fit together into a theme	Codes organised into broader themes that say something specific about the research
4	Review themes	Modify and develop the preliminary themes	More organised and logical set of themes and sub-themes
5	Define themes	Identify what each theme is saying	Thematic map illustrating relationships between themes along with a narrative
6	Write-up	Compile report	Findings

The self-assessment documents were initially reviewed, and a set of search terms were selected to help identify relevant clusters of text for coding. Documents were searched for the keywords *"sustain", "green", "environmental", "SDG", "circular economy"* and *"climate"* respectively. In step 2, a set of codes were generated and are presented in Table 2.

Table 2. Codes identified in step 2 of Braun & Clarke's method

Code	Description
M-SDG	SDG's were mapped to particular modules within a programme.
M-PA/PO	PA areas were mapped to programme outcomes highlighting how Programme outcomes were mapped to Programme Area 7.
S-SP	Description of where sustainability is in the university's strategic plan.
S-RE	Description of where sustainability is in the university's regional contribution.
SCM - PO	A module specifically addressing sustainability was identified as a strong contributor to a programme outcome.
SCM - PA	A module specifically addressing sustainability was identified as a strong contributor to a programme area.

Following the identification of codes, a set of subcodes were generated, particularly to examine the codes SCM – PO, and SCM – PA. The PO's can be thought of as being divided into 4 technical outcomes, including PO1 *Knowledge & Understanding*, PO2 *Problem Analysis*, *PO3 Design* and *PO4 Investigation,* and non-technical outcomes including *PO5 Professional and Ethical Responsibilities, PO6 Teamwork & Lifelong learning, PO7 Communication* and PO8 *Management*. The PA's which emerged from the thematic analysis where PA6 *Engineering practice* and PA7

Sustainability. The summary of the subcodes considered for the thematic analysis are presented in Table 3.

Table 3. Summary of subcodes identified in stage 2 of Braun & Clarke's method

Subcode	Description
SCM - PON	A module specifically addressing sustainability was identified as a strong contributor to a programme outcome N.
SCM - PAN	A module specifically addressing sustainability was identified as a strong contributor to a programme area N.

4 RESULTS

Table 4 illustrates how each Programme's (PG's) self-assessment report compared across the various codes identified. As mentioned in the methodology section, a cluster of codes in SCM-PO and SCM-PA were identified and resulted in a set of subcodes being developed to explore these codes in more detail.

Table 4. Coding density by discipline and additionally by NFQ level

	Programme (PG)										
Code	**PG1**	**PG2**	**PG3**	**PG4**	**PG5**	**PG6**	**PG7**	**PG8**	**PG9**	**PG10**	**PG11**
M-SDG	4	2	2	1	1	1	1	3	1	1	1
M-PA/PO	0	1	1	1	1	0	0	0	0	0	0
S-SP	0	1	1	1	1	0	0	0	0	0	0
S-RE	0	1	1	1	1	0	0	0	0	0	0
SCM -PO	11	5	4	2	2	3	13	9	1	10	18
SCM -PA	10	0	0	0	0	7	16	14	6	11	21

Table 5. illustrates the breakdown of the strong contributor modules to each PO and PA identified in the self-assessment reports. These codes clustered on PO5, *Professional & Ethical responsibilities* and PA7 *Sustainability* which is unsurprising as an engineer's responsibility to protect the environment is explicitly written in the Engineers Ireland Code of Ethics (Engineers Ireland 2023). Of interest is the cluster of codes in PO3 *Design,* 12 modules identified as strong contributors to sustainability were mapped to this PO, implying that Engineering Programmes at University A use design modules to convey the importance of sustainability to students, this implication is bolstered in the case studies presented later.

Table 5. Sub-coding density by discipline

Subcode	PG1	PG2	PG3	PG4	PG5	PG6	PG7	PG8	PG9	PG10	PG11
SCM - PO1	0	0	0	0	0	0	0	0	0	1	2
SCM - PO2	0	1	1	0	0	0	2	1	0	2	2
SCM - PO3	0	0	0	1	1	1	4	1	0	2	2
SCM - PO4	0	0	0	0	0	0	0	1	0	0	5
SCM - PO5	6	4	3	1	1	2	6	3	1	4	5
SCM - PO6	2	0	0	0	0	0	0	2	0	0	1
SCM - PO7	2	0	0	0	0	0	0	1	0	0	0
SCM - PO8	1	0	0	0	0	0	1	0	0	1	1
SCM - PA2	1	0	0	0	0	0	0	0	0	0	0
SCM - PA6	1	0	0	0	0	0	0	0	0	0	0
SCM - PA7	8	0	0	0	0	7	16	14	6	11	20

4.1 Theme 1: Commitment to SDGs at a strategic level

All programmes declare commitment to the SDGs at a strategic level. An analysis using the EU KnowSDGs (https://knowsdgs.jrc.ec.europa.eu/) tool is used by programmes used to identify the key SDGs. Furthermore, all programmes include statements of support of SDGs at both departmental and faculty level.

A selection of rich data supporting theme 1:

“. . . aims to bring about a sustainable and fundamental change in behaviour and influence a best practice culture across the University, on all campuses through embracing the UN SDGs.”

“. . . committed to embracing Education for Sustainable Development as an integral element of the SDG on quality education as a key enabler of all the other SDGs”

“. . . by 2030 ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and nonviolence, global citizenship and appreciation of cultural diversity and of culture’s contribution to sustainable development”

4.2 Theme 2: Alignment with Programme Outcomes (POs)

Programme Outcomes are broad statements identifying learning parameters, content, and relationships between content areas. Many of the programmes under review were designed prior to the 2021 Engineers Ireland criteria, therefore it is reasonable that the SDGs were not explicitly included in the programme design process. However, there is evidence of alignment of elements of sustainability across all PO’s. This is particularly evident in relation to *PO2 Problem Analysis, PO3 Design, PO4 Investigation and PO5 Professional and Ethical Responsibilities.*

4.3 Theme 3: Alignment with new programme area of sustainability

Programme Areas are necessary to facilitate the engineering graduate's achievement of the Programme Outcomes. An example of the interpretation of Engineers Ireland PO's to PA7 extracted from a self-assessment report can be seen in Table 6.

Table 6. Example of the interpretation of EI POs to PA7

Engineers Ireland PO	Example interpretation of PA7
Knowledge and Understanding	Introduction to SDGs and relevance to engineering practice, manufactured products and project outputs
Problem Analysis	Query the sustainability of existing assumptions and processes
Design	Design for sustainability. Impact of SDGs on future design requirements
Investigation	Acknowledging complexities and looking for links and synergies in problem solutions.
Professional & Ethical Responsibilities	Consideration of relevant SDGs in educational development and professional practice.
Teamwork & Lifelong Learning	Inclusion of external factors and users in the commitment to sustainable action in engineering activities.
Communication	Promoting dialogue and negotiation across diverse groups in addressing SDGs.
Engineering Management	Involving people in joint analysis, planning and control of decisions.

5 SUMMARY AND ACKNOWLEDGMENTS

An outcome of the analysis of codes and subcodes were the identification of 3 exemplary programmes at University A in terms of how sustainability was being embedded within the taught content of the programme, an Energy programme delivered at Bachelor level and 2 Mechanical programmes delivered at Bachelor and Master level, the latter of which will be taken together.

5.1 Energy Engineering programme

In this programme, 20 codes were identified presenting modules as strong contributors to PA7 *Sustainability*. Four modules in particular, contributed 72% of this coding density. This is not a prescribed approach to addressing PA7, however the coding indicates that modules addressing PA7 were also strong contributors to PO4 *Investigation and* PO5 *Professional & Ethical Responsibilities.* Implying that sustainability is embedded in experimental design and simulation. Of particular note is the 15 ECTS work placement module, where students get first-hand experience of their professional and ethical responsibilities as part of the ten-week placement.

Typically, students undergo specific training for the company they are placed in, and this will often reinforce these responsibilities. Working under the guidance of a mentor, students get continual feedback regarding their professional performance and expectations as engineers, helping students to grow personally and professionally.

The new programme area PA7 *Sustainability,* is evidenced across all four years of the programme with a higher proportion in years 2 and 4. With respect to assessment, 77% of modules with codes contributing to sustainability in POs, are assessed fully via continuous assessment. Similarly, 75% of modules contributing to PA7 are assessed fully via continuous assessment. A first-year foundation module of particular interest related to Climate Change & Energy and contributes to PA7 as well as *PO1 Knowledge and Understanding, PO2 Problem Analysis, PO4 Investigation* and *PO7 Communication.*

5.2 Mechanical Engineering programmes

In these programmes, 16 codes were recorded relating to a module specifically addressing sustainability being identified as a strong contributor to PA7 *Sustainability*. This is not a prescribed approach to addressing PA7, however the coding indicates that modules addressing PA7 were also strong contributors to *PO2 Problem Analysis, PO3 Design, PO5 Professional & Ethical Responsibilities* and *PO8 Engineering Management* with thirteen codes identified relating to a module specifically addressing sustainability being identified as strong contributors. This suggests that while Sustainability is a Programme Area rather than a Programme Outcome, it permeates the Programme Outcomes.

Of particular note with regard to strong contributors to PA7 are the capstone design project on the Master's Programme, a 30 ECTS module in which students must consider all relevant societal impacts, including environmental impacts of their designs within the project thesis and the capstone design project on the Bachelors Programme (a 10 ECTS module where students must critically assess the project against appropriate design, safety, commercial and ethical criteria). Sustainability is evidenced across years 1,2 and 4 of the Bachelor programme with a particularly strong emphasis placed on sustainability in the Master programme, with 89% of modules contributing to sustainability being assessed through course work; including continuous assessment, lab work and reports. Only 3 modules contributing to sustainability contain a written examination and in no case is this 100% of the assessment on these modules.

5.3 Conclusions

The main findings were that University A made a strong commitment to align all programmes to the SDGs at a strategic level, embedded sustainability across multiple POs and identified strong contributor modules to *PA7 Sustainability* in a similar approach to that of the assessment of POs.

5.4 Limitations

A limitation of this study is that self-assessment reports are exactly that, self-assessed measures of achievement. In the estimation of Engineers Ireland, often individual academics underestimate their achievements in their self-assessments, and much more detail can be found in the individual evidence folders, which contain among other things, exam scripts, external examiner reports and module descriptors, as well as supporting evidence provided at accreditation visits and captured in the panel reports, which are prepared by external academics and industry representatives. There is a richness of data to explore on how sustainability is embedded in these programmes that goes far beyond the self-assessment reports that lies outside the scope of this paper.

5.6 Recommendations & future work

This paper is not conceived as a final product, but as an initial step in a wider research project. It demonstrates the accreditation process can now capture best practice examples of how sustainability is being embedded in engineering curricula across Ireland. It may be tentatively concluded that there has been an increase in awareness of the SDGs and sustainability practices in engineering education. These findings, however, do not establish a causal link between the new accreditation criteria and an increase in sustainability in engineering education. This would require a review of the self-assessment reports longitudinally to assess the relative influence of the previous Engineers Ireland criteria, as well as the mission statement of the University at the last accreditation visit. Further research is recommended, specifically in-depth interviews with accreditation panellists and the programme team would provide an understanding of the perceived gaps in the self-assessment reports, expansion of the dataset to include all HEI's who have been assessed against the 2021 accreditation criteria, and a review of the additional programme evidence provided in the submission for accreditation. These findings will be presented to the Engineers Ireland accreditation board and form part of the conversation about how the Engineers Ireland accreditation criteria are reviewed to reflect best practice in engineering education.

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Supporting Innovation in Higher Education: How Higher Education Can Support Innovative Teaching Practices

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ABSTRACT

Educational institutions that want to successfully innovate regarding the education they provide must synchronise organisational growth with educational growth. To support such innovation, a maturity model can help identify successful teaching and learning practices by encouraging experimentation, collaboration and alignment with strategic goals. Although maturity models that support staff in the process of innovating education are valuable, they are scarce. This phenomenological study explored the views of staff from the Centre for Expertise in Learning and Teaching (CELT) on readiness for innovation at the University of Twente (UT). We surveyed staff members who were actively involved in projects or teacher initiatives aimed at educational innovation. The questionnaire consisted of 137 closed-ended multiple-choice questions (e.g. 'Is teaching support guided by the latest research findings?') and answers on a five-point scale ('Not', 'Partly', 'Largely', 'Fully' and 'Don't know'). The survey's structure was based on that of the maturity model. The questions were divided into five categories of processes: learning (directly affecting pedagogy), development (related to the creation and maintenance of resources), support (related to support and operational management), evaluation (related to evaluation and quality control throughout its lifecycle) and organisation (related to institutional planning and management). After the survey results were analysed, respondents were invited to reflect on its outcomes, share their insights and suggest possible explanations for the results. In this paper, we present the educational support staff's maturity model results

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and discuss how these results can influence the effects of teachers' innovative practices.

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1 INTRODUCTION

1.1 Innovation in Higher Education

This study examines how an innovative educational approach maturity model can be used effectively to not only help higher education institutions (HEIs) innovate regarding their teaching practices, but also to provide a framework enabling staff professional development. This model can help staff identify areas needing improvements and provide guidance on where and how to implement improvements within an organisation's larger context to achieve maximum effect (Chapel, DePryck, and Buunk 2022). This paper presents new research data and insights which can help improve the maturity model, making it valuable to teaching staff who want to increase educational innovation. In recent years, challenges posed by rapid changes to educational approaches and the need for future-proof education have become increasingly apparent. In response, HEIs worldwide have sought to improve their teaching practices through innovation. Despite their efforts, many HEIs struggle to identify effective strategies for making these changes. This article presents the challenge-based learning (CBL) maturity model developed specifically for HEI support and teaching staff who want to innovate in education (Chan et al. 2017; Jiang et al. 2020; Snow Andrade 2020). This tool enables HEI staff to assess current innovations and identify areas for potential innovation in teaching practices. The tool can also guide teachers' development by helping them understand how the educational process contributes to educational innovation. The model focuses on the quality of five main processes essential to success: learning, development, support, evaluation, and organisation (Figure 1).

Learning	**Processess that directly iimpact the pedagogical aspect of the innovative educational approach** *This process deals with the core aspect of education, the acquisition of knowledge, skills, and attitudes. The primary focus is on innovatieve aspects of the curriculum and the desired learning outcomes*
Development	**Processess surrounding the creation and maintenance of resources for innovating education** *This process involves learning and support of the teaching staff, infrastructure, and facilities required for delivering quality education.*
Support	**Processess surrounding the support and operational management of the innovation** *This process involves the provision of support services to learners to ensure their holistic development such as health counseling and career guidance.*
Evaluation	**Processess surrounding the evaluation and quality control of the innovation** *This process involves the continuous monitoring and evaluation of the education delivery process of the innovative approach, such as curriculum evaluation, teacher evaluation, and learner assessment.*
Organisation	**Processess associated with institutional planning and management** *This process involves the management and administration of the institution such as governance, finance, and resource allocation.*

Figure 1. The five process areas that facilitate the delivery of education (Marshall, 2007).

Based on an extensive literature review, we identified the 35 sub-processes necessary for successful innovation in education, which were divided into practices. The CBL maturity model can be divided into three main levels: organisational, programme and course (Chapel and DePryck 2022).

1.2 Maturity Model to Support Innovation

HEIs are expected to deliver effective, high-quality education (Avvisati, Jacotin, en Vincent-Lancrin 2014; Biggs en Tang 2011). Their effectiveness depends not only on the quality of their teaching staff, but also on various processes that facilitate the delivery of education (Chapel et al. 2022; Marshall 2007)). By breaking down complex educational systems into related process areas that can be examined independently, staff can independently use the CBL maturity model to evaluate the effectiveness of planned innovation after readiness has been identified at the institutional level. For example, if the item ‘Teaching staff are recognised and rewarded for their engagement with innovation’ is answered on the institutional level using ‘Not’, this provides teaching staff with a valuable starting point for assessing the feasibility of their innovation ideas and informing their decisions on moving forward. Research has found that maturity models can be powerful tools for making meaningful change in education (Tocto-Cano e.a. 2020). In addition, these models encourage teachers to become more reflective practitioners by motivating them to consider the larger implications of their decisions when introducing new practices into their teaching curricula (Demir en Kocabaş 2010; Gunsberg e.a. 2018). However, despite the potential benefits, there are still challenges associated with successfully applying these models within HEIs (Eden et al. 2016).

1.3 Supporting Innovation

Because the University of Twente (UT) wants to prepare students to obtain knowledge outside their own fields of study and take into consideration the societal effects of their actions, it has for many years used a project-based education called the Twente Onderwijs Model (TOM) as the main educational approach for all bachelor’s programmes. UT has also used CBL initiatives in the past. By running CBL pilots, ECIU University[2] has played an important role in implementing CBL within UT (Chapel et al. 2022).. Thus, to identify and analyse the readiness of educational support for CBL innovation, Marshall’s e-learning Maturity Model was adjusted into a maturity model for CBL. Notably, this adjusted model is not limited to use with CBL, but can be used with any innovative approach to education.

1.4 Centre of Expertise in Learning and Teaching

The Centre for Expertise in Learning and Teaching (CELT)[3] is an academic department within UT that plays an important role in enhancing students’ educational experiences by supporting and guiding teaching staff. CELT provides teaching staff with various services, including help designing courses and modules, accreditation of programmes, professional development opportunities and new educational approaches to teaching practice. For instance, UT’s strategic plan, Shaping 2030, introduces CBL’s role in UT’s education and encourages teachers to experiment with

[2] https://www.eciu.eu/

[3] https://www.utwente.nl/en/ces/celt/

it, with the ultimate aim of positioning UT staff as pioneers in innovative education in alignment with the university's mid-term to long-term goals. As a result, CELT has incorporated CBL expertise into its support services, providing CBL training opportunities and assigning educational advisors with specialised CBL knowledge.

2 METHODOLOGY

2.1 Questionnaire

This article presents a phenomenological research study exploring the perspectives of CELT staff regarding UT's readiness for innovation. Although phenomenological research may not typically produce generalisable findings, it can provide insights that help identify and understand a particular topic (Dukes 1984; Sloan en Bowe 2014). Respondents were asked to complete a questionnaire consisting of 138 closed-ended multiple-choice questions, their answers to which indicated the extent of their agreement with a series of statements. The answer choices, based on a five-point scale, included 'Not', 'Partly', 'Largely', 'Fully' and 'Don't know'. The survey questions were categorised according to the five main areas of the CBL maturity model and did not allow for elaboration or comment. The responses were analysed to identify patterns, trends and key themes. After these were identified, the descriptive analysis of the results was shared with the respondents, who were individually asked to verbally reflect on them. Reflection prompts were used to scaffold the responses. The analysis of these results focused on identifying similarities and differences in the respondents' experiences and perceptions of the phenomenon, as well as the underlying themes or patterns reflected in audio notes of their responses

2.2 Problem Statement

The pilot test of the CBL maturity model tool made evident that there were considerable differences in the ratings provided by support staff (i.e. at the institutional level). This raised concerns about a lack of clarity or consensus regarding the support systems available to teaching staff who want to innovate their practices. This study aimed to increase the understanding of these discrepancies and the reasons behind them.

3 RESULTS

3.1 Descriptive Analysis

The CBL maturity model instrument was filled out by four CELT members who were involved in the implementation of CBL at UT (see Table 1 for their roles and years of experience).

***Table** 1. Job Function and Experience of Respondents*

Role within CELT		Experience (years)
R1	Coordinator Teacher Professional Development	25
R2	Coordinator Senior Teaching Qualification	30
R3	Challenge-based Learning Expert	10
R4	Challenge-based Learning Expert	2

Of the four, R3 and R4 were closely involved with CBL initiatives, while R1 and R2 had a more generic overview of them. The main process scale included subprocesses of the main processes that had Cronbach's alpha values $\geq$ 0.7 (75 items) (Table 2).

***Table 2.** Cronbach´s Alpha Main Processes*

	Cronbach´s Alpha	N	M	SD
Development	0.984	37	41.5	31.0
Learning	0.895	8	12.3	5.9
Support	0.943	10	14.5	8.7
Evaluation	0.957	13	13.8	12.3
Organisation	0.917	7	6.0	5.8

The option 'Don't know' was the one most selected by respondents, followed by 'Not', and together these two accounted for more than 50% of the responses for each process. As Figure 2 shows, when the responses 'Don't know' and 'Not' were combined, there was a significant difference between R1, R2 and R3 on one hand and R4 on the other.

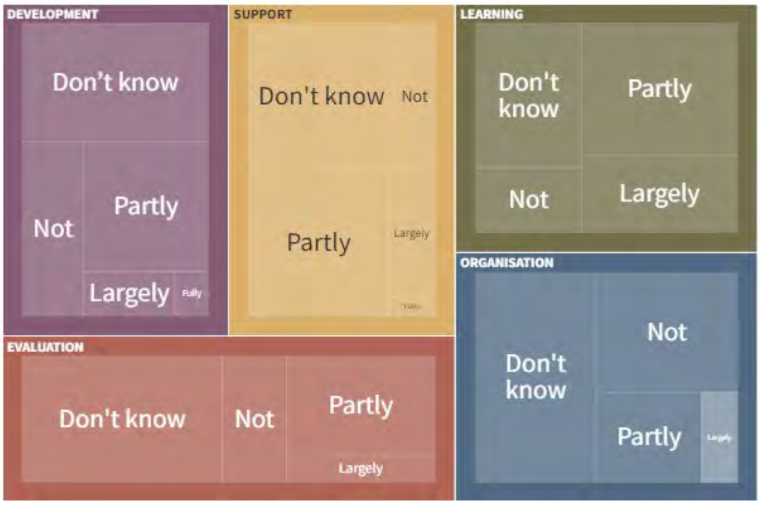

Figure 2. Ratio of answer options.

Most 'Don't know' and 'Not' items were related to finance or policy. Figure 3 shows four items, which were scored as R1, R2 and R3 = 'Don't know' and R4 = 'Not'.

***Figure 3**. Items related to the process organisation: above-average answer 'Don't know'.*

1. *Information on the effectiveness of design and development support guides the strategic and operational planning of CBL.*
2. *The effect of design and development support guides the allocation of resources for support. '*
3. *Information from CBL reviews guides CBL initiative planning.*
4. *Risk assessments of failed CBL initiatives are formally reviewed to identify factors to include in the risk analysis and mitigation plans of existing and future CBL initiatives.*

Figure 4 shows items that the respondents seemed to agree on and for which the results showed an above-average readiness (R1, R2 and R3 = 'Partly' and R4 = 'Largely') and that mainly questioned the pedagogical support and resources available to the teaching staff.

1. *Teaching staff are provided with information on how CBL pedagogy support a range of student cognitive outcomes.*
2. *CBL design and (re)development procedures include assistance for teaching staff in changing pedagogies.*
3. *Teaching staff are provided with support resources (including training, guidelines, and examples) on how to assist students in developing skills.*

Figure 4. Items with above-average readiness.

3.2 Respondents' Reflections

In their verbal reflections, the respondents were asked to provide insights into the trends of the analysis. R1 and R3 submitted their reflections, which showed that support for CBL was just beginning when the surveys were completed and the educational approach was relatively new to HEI. They noted that a lack of both knowledge of the approach and visibility of available support structures contributed to the high rate of 'Don't know' responses. R1 explained that while support was available, it was not centralised, and information was not readily available. R3 confirmed that support was not visible and information not structured. Thus, the respondents stressed the need to rethink the way in which innovation support is provided, including the professionalisation of the support staff itself and the acquisition of knowledge to address the complexity of education. Furthermore, R1 noted that the 'Don't know' and 'Not' answers were guided by a lack of both awareness of policy developments and a clear vision regarding educational innovation. According to R1, support would have been more systematic and clearly organised if there had been better understanding of who had the power to make decisions. In addition, R3 reflected on the message that CELT conveys when it presents support staff as advisers: "*As an advisor, you tell [teachers] what to do, but they don't need advice, they need someone who stands beside them*'. R3 suggested that teachers must be more engaged and encouraged to drive innovation themselves while having the ability to access continuous hands-on support for innovating their practices. Lastly, R1 expressed the belief that CELT plays a critical role in providing inspiration, co-creation and feedback that promotes evidence-informed educational innovation. R1 emphasised that the support department should be involved in policy development and defining a clear university-wide vision to guide support offerings.

CONCLUSION

This paper provides a comprehensive analysis of the responses from educational support staff at UT, using the CBL maturity model instrument, to assess UT's institutional readiness for educational innovation. It also examines the current manifestation of support structures within the institution and discusses potential improvements for more effective scaffolding of educational innovation.This study highlighted a significant challenge faced by support structures when introducing educational innovation approaches like CBL into higher education practices - a lack of awareness and visibility. To address this issue, several key recommendations are proposed.Firstly, it is crucial to allocate sufficient time and opportunities for educational support staff to acquire the necessary knowledge and skills to navigate the complexities associated with introducing new elements into education. Continuous professional development should be prioritized to ensure support staff are equipped to effectively support educational innovation.Secondly, establishing a clear connection between the educational support department and university policymakers can lead to a more systematic and organized support structure. Such a connection would enhance the effectiveness and success of educational innovation initiatives by aligning the support provided with the strategic goals and vision of the university.Lastly, educational support staff must assume a crucial responsibility for promoting evidence-based educational innovation. They should actively participate in the development of policies and collaborate with stakeholders to define a shared vision that guides the university's support services. By doing so, support staff can provide inspiration, engage in co-creation, and offer valuable feedback, ultimately fostering a culture of evidence-based educational innovation.Implementing these recommendations will lead to improved support structures and enhance the effects of educational innovation on teaching staff. By providing a strong foundation of support, universities can effectively facilitate teaching staff in their pursuit of innovative practices.

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THE BELL ACADEMY: A BRIDGE SEMESTER WHERE ENGINEERING STUDENTS TRANSFORM INTO STUDENT ENGINEERS WHO THRIVE IN INDUSTRY PLACEMENTS

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ABSTRACT

Iron Range Engineering is an innovative learning program using project-based and work-based pedagogies. The Bell Academy (BA) is a semester-long bridge experience between the first two years of STEM foundation and the final two years spent in full-time industry co-op placements. The curriculum within the academy is delivered within three domains: technical, design, and professional. The transformation to thriving as a student engineer in an industry placement is intentionally embedded in each stage of the program as students develop higher levels of self-awareness, professional responsibility, and self-directedness.

Students not only gain technical engineering knowledge, but also apply that knowledge within team-based, ill-structured design projects, acting as engineering consultants to industry clients. Technical learning is delivered in one-credit modules, which supports both the development of the individual as a student engineer and the execution of the project. Professional competencies are learned in-situ as teams encounter natural struggles. Development is supported through workshops, which cover topics such as conflict management, leadership, technical writing, data science, public speaking, inclusive action, etc. Through iterative assignments and practice, such as resume development, negotiation, and interviewing, students develop a skills portfolio to identify and acquire a position to begin and maintain their career.

Through more than a decade of implementation, several unique learning strategies have been developed and refined. The paper will briefly describe the model used and provide the strategies as potential tools for adaptation and implementation in engineering programs worldwide.

1 INTRODUCTION

Throughout its history, engineering education has seen periods of innovation and growth in the education and identity development of future engineers. The past quarter century is a period where scholarly activities and research from around the globe have called for an unprecedented need for the evolution of engineering education so that graduates meet the needs of a society that is experiencing an accelerated rate of change (Sorby and Fortenberry 2021).

Iron Range Engineering (IRE) began in 2009 as a regionally-based, project-based learning (PBL) upper-division (i.e., last two years of bachelor's degree) program based on the Aalborg University PBL model (Kolmos, Fink, and Krogh 2007). Students completed their lower-division (i.e., first two years) requirements (i.e., calculus, physics, chemistry, general education, and foundational engineering skills) at a regional community college. At the time, PBL was not common in the United States and was initially met with pessimism by higher education peers and some in industry. Over the next decade, PBL became much more accepted and desired. Recognition grew with IRE being awarded an ABET Innovation Award in 2017 and Ruth Graham’s MIT commissioned report identifying IRE as one the current and emerging world leaders in this transformation of engineering education in 2018 because of its exploration and innovation (Graham 2018; Ulseth 2016; Johnson and Ulseth 2016). It was also clear that future innovation was needed to both further develop the PBL curriculum and grow the number of students who could be served by the model.

In August 2019, after some initial small-scale piloting, 20 students from community colleges across the United States formed the program's first cohort for a co-op work-based learning model adapted from the Charles Sturt Engineering program (Morgan et al. 2021). Upon completion of their community college program, student engineers enter the BA for one semester followed by 24 months of paid co-op in industry, culminating in graduation with a Bachelor of Science in Engineering (Johnson, Ulseth, and Wang 2018).

The BA is a primarily in-person, intensive semester-long experience providing students with a convergent, transformative experience from their prior life and education experiences to meet their developmental needs for success in a four-semester co-op placement. The academy explicitly focuses on developing student technical, professional, and design competencies, along with attainment of the co-op learning experience and the building of strong social connections. Students are also encouraged to seek out and create value in their learning experiences.

The outcomes of the BA (Ulseth, Johnson, and Kennedy 2021), include:

- Gaining the knowledge and skills necessary to find, interview for, and acquire co-op positions.
- Learning and implementing an engineering design process while completing a design project for an industry client.
- Preparing professionally to thrive as contributors on engineering teams while on co-op placement.
- Developing self-directed learning (SDL) capabilities as technical learners as they advance their acquisition of core technical knowledge and prepare to undertake advanced, student-led technical coursework.

This paper aims to show the theoretical and practical basis of how IRE helps students achieve these outcomes by the end of the academy, adequately preparing them for their first industry co-op placement through design, professional, and technical learning.

2 RESEARCH BASIS

Four key themes for transforming engineering education manifested themselves in the first 9 years of development and implementation of the original IRE model (Johnson, Ulseth, and Raich 2022), which would be used in the next innovation of the curriculum. **Authenticity** is a necessary component of the learning experience. Student motivation is optimized when they feel they are doing authentic work that has value and impact. The **curriculum must reflect the desired outcomes**. Important aspects which explicitly foster student development of desired outcomes for the educational model must be purposefully built into the curriculum. In this model, the development of technical, professional, and design competencies are highly and equally valued. **Strong social connections** are necessary and thus relationships between faculty-to-students and student-to-student must be purposefully cultivated. Physical spaces and a culture of trust, joy, collaboration, openness, purposeful inclusiveness, and courage empower relationship building and the development of a common set of professional goals. Transformative educational models are built through scaffolding of an **entrepreneurial mindset**. An entrepreneurial mindset with a purposeful approach to continuous improvement is necessary to not only keep the curricular innovation alive, but to also ensure the educational model and program stays ever relevant and of value for both the students and the communities served during this period of rapid change in the world.

Each of these four themes emerged within study of the IRE program, but they ultimately align with the widely researched and implemented Universal Design for Learning (UDL), a research-based framework for supporting the teaching and learning for all people. Therefore, this paper frames the practices of the BA through the lens of the UDL framework. The UDL framework (Rose 2000) consists of three main principles that are based on research in the learning sciences and cognitive neuroscience. The first principle is providing **multiple means of engagement** (the "why" of learning), and its guidelines support development of the affective network of the brain, resulting in learners that are purposeful and motivated. The second principle is **providing multiple means of representation** (the "what" of learning), and its guidelines support the recognition networks of the brain to develop learners that are resourceful and knowledgeable. The third principle is **providing multiple means of action and expression** (the "how" of learning), and its guidelines support the strategic networks of the brain and develop learners that are strategic and goal directed.

3 METHODOLOGY

As the only undergraduate engineering bridge program of this caliber, a deeper dive into the framework and practices was warranted. This study was performed by the authors as a research team, which consisted of two program directors, two tenure-track faculty members, and a partner community college administrator.

After reflecting on the unique processes and practices utilized within the BA and researching UDL principles, the research team recognized an opportunity to align theory and practice with the goal of supporting other bridge programs and educational experiences. To support this dissemination, an analysis of the practices of the BA was performed using each of the three principles of UDL – the "why", the "what", and the "how". UDL offers a variety of best practices in each of these areas; a list of best practices is shown in Fig. 1. While these best practices only include a portion of those suggested by the overall UDL framework, the research team worked together to highlight those intentionally implemented and aligned with practices in the BA.

Results will be reported in the form of recommendations for implementation. The recommendations were developed by the research team after the individual sections of the "why", "what", and "how" were developed, leading to overarching themes and high-impact practices to be highlighted. Because not all programs have the ability to overhaul an entire program or start a new program, the recommendations are designed to be approachable, regardless of the context.

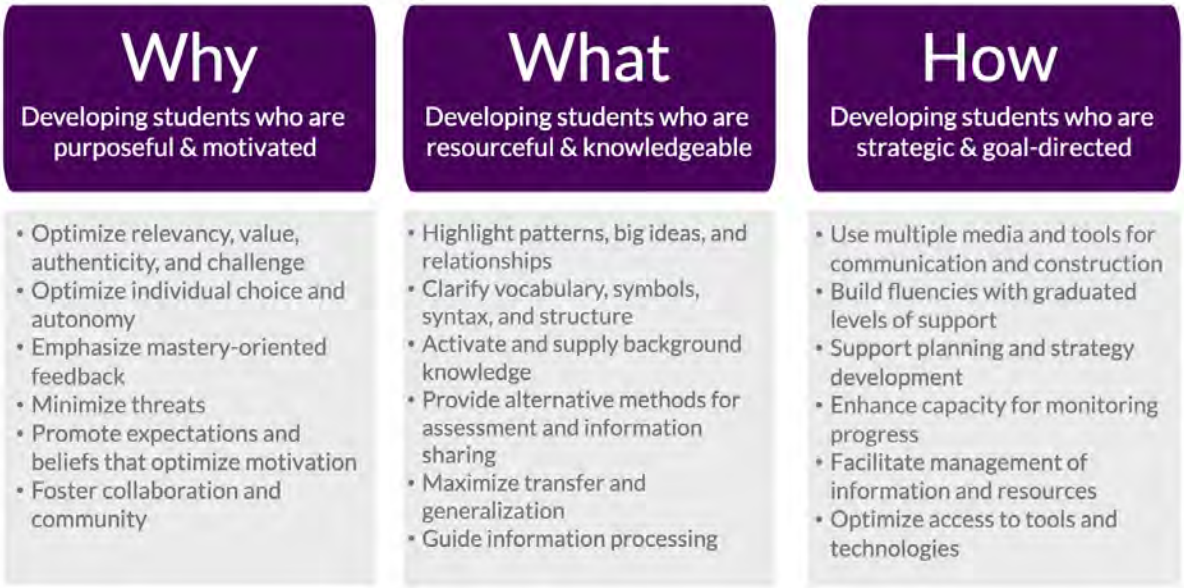

Fig. 1. A list of Universal Design for Learning best practices that are integrated in the BA. Adapted from CAST (CAST 2018).

4 THE "WHY"

The evidence presented in this section supports the design and implementation of the academy with the overall goal of "the why" being the development of expert learners who are purposeful and motivated. Intentionally creating that space allows the foundation to be built of students' interest, effort, persistence, and self-regulation within their engineering education through those best practices highlighted within the "Why" in Fig. *1*.

The BA curriculum is designed to maximize and promote student motivation to learn, be authentic, and be challenged (Ulseth 2016). Ryan and Deci's self-determination theory (SDT) serves as the foundation for empowering motivation with autonomy, competence, and social connectedness as the triad of basic human needs that when optimized, maximize motivation (Ryan and Deci 2000). During the BA, students are given choice and ownership to promote autonomy through means such as performing authentic deep learning activities in technical competencies that are challenging without seeming impossible, choosing a topic of choice for presentations and discussions, designing their path and engineering focus area through courses taken, and others. From the beginning of the BA, students are immersed in developing their understanding of and skill in executing SDL (Ulseth and Johnson 2017) through personal self-assessments and learning journals, requiring reflection.

Each student that enters the academy is part of a cohort who will navigate their path through the 2.5 year program together. Learning in the academy often takes place in small, collaborative teams within all three aspects of student learning (i.e., design, professional, technical). This ensures that student engineers are capable of working on productive cross-functional teams when they arrive at their engineering co-ops (Davis and Ulseth 2013). Teamwork is included in design projects, in classroom activities, and with all faculty and staff members. High levels of community and collaboration are also encouraged through regularly scheduled student-life events, with faculty and staff also involved, so students are involved with one another outside of the classroom, normalizing the ability for open communication with all.

Mastery-oriented feedback using a scale focused on a helix of continuous improvement is central to the learner-teacher relationship (Singelmann, Wang, and Christensen 2023; Christensen et al. 2023). This feedback is based on a 5-Point grading scale, detailed in Singelmann et al. (Singelmann, Wang, and Christensen 2023), taking the focus away from a traditional grades-based outcome focus to a growth-mindset focus (Dweck 2007). While student engineers receive developmental feedback from their professors, they also are scaffolded to develop high levels of self-assessment capability through technical reflections weekly and across all courses (Johnson and Ulseth 2016). Metacognition supports self-assessment and SDL processes. One example of this is that students write a metacognitive memo inspired by Tarricone's Taxonomy of Metacognition (Tarricone 2011).

Throughout the academy, it is expected that students learn and practice the professional conduct necessary for future placements in industry. There are daily check-ins scheduled each morning to practice consistent messaging across multiple domains, such as scheduling, time management, identity development, technical writing skills, data science tidbits, etc. that *consistently* convey these expectations and the beliefs needed to support the students in their growth.

The program overall aims to minimize threats, creating safe space to make mistakes in this learning process. This is done through iterative, low-stakes opportunities to practice and develop professional competencies and identity. A strong example of the minimization of threats is that while IRE does not place students in their industry positions, scaffolding is provided to help students acquire those positions. By holding iterative assignments and practice that are built into the curriculum, students develop a skills portfolio to identify and acquire a position to begin and maintain their career. These assignments and practice include activities such as career development specific workshop engagement, resume development, negotiation practice, and mock interviewing. Because of the success of IRE students at industry placements in the past, IRE can hold their own career fairs, both on-site and virtually, to further support students in successfully navigating their transition to full-time engineering.

5 THE "WHAT"

To successfully prepare students in all three curricular domains in the BA, students have many opportunities to receive information and apply it. The technical, design, and professionalism learning spaces promote development of students who are resourceful and knowledgeable through the best practices highlighted within the "What" in Fig. *1*.

All technical learning in the BA is delivered in one-credit modules. Through formatting each engineering competency (e.g., Thermodynamics, Electronics, AC Circuits, Statistics, etc.) as one-credit versus a traditional three-credit format, students can activate their prior learning and build upon it to supply additional background information to support the application to design projects and ultimately their industry placements. All one-credit modules are focused on two to six fundamental principles (FPs), which highlight the patterns, critical features, big ideas, and relationships behind a given topic. Instead of trying to teach students everything, the goal is to teach them enough to be confident in the FPs, in calculation, application, and communication. This is supported by clarifying key vocabulary, symbols, syntax, and structure for each of the fundamental principles. Students are also held accountable for continuing to activate their background knowledge about the fundamental principles in future courses, as well as in their design projects and industry placements. To allow for alternative methods for information sharing, the assessment of technical learning is offered in multiple ways (e.g., oral exams [Christensen et al. 2023], low-stakes quizzes, deep-learning activities, etc.).

Students are also able to apply and develop their engineering learning through ill-structured design projects. During the BA, students work in teams of four to five as engineering consultants with industry clients. An IRE staff member also serves as a facilitator with the project to assure that relations and quality of work are as expected. Through these design projects, students can maximize their transfer of technical knowledge to new contexts. Some technical information they may already be familiar with to generalize to the project, but other types of information may have to be obtained through SDL methods, requiring students to focus on how to embed new ideas into their current understanding. Students have one hour of training each week on the principles and practices of SDL to support them in their design work.

Within the BA, many professional competencies are learned in-situ as teams encounter natural struggles. Development is supported and scaffolded through workshops, which cover a variety of topics (e.g., conflict management, leadership, technical writing, data science, public speaking, modern tools, inclusive action, etc.). These workshops come in two forms: 1 to 1.5 hour long workshops that happen individually or 15 minute workshops every week of the BA for 16 weeks. Some of the topics are covered every BA as they have been important to each set of students, but some topics have evolved over time on a needs-basis and perceived from student outcomes and feedback. Because of their current work on engineering design teams, students are able to transfer and apply their workshop learning to situations in real-time. Rather than leaving professional development up to chance, these workshops guide information processing by creating time and space for students to intentionally practice and reflect on development of professional skills.

6 THE “HOW”

The BA is designed to support development of students who are strategic and goal-directed through the best practices highlighted within the “How” in Fig. *1*.

The BA is delivered to emulate industry structure to prepare student engineers to thrive as working engineers, which in the two years after BA, will also include being full-time students. Students are expected to work on their design, professional, and technical learning for ~40 hours each week for 16 weeks, which takes place during the hours of about 8 am to 4 pm each day and are structured to allow instructors to make sure students have access to information, resources, tools, and technologies to support their learning. An additional 12-15 hours per week are dedicated to schoolwork and job applications. Work-based learning helps to build an engineering identity (Johnson, Ulseth, and Raich 2022), and the BA intentionally builds that foundation.

All learning in the BA is digitally mediated meaning that there will be both asynchronous and synchronous portions of learning, with some students being on-site in Virginia, MN together and others who primarily be on Zoom in a hybrid fashion due to limitations on them being on-site. Technology has been integrated on campus to allow remote students to be a regular part of discussion and breakout groups within full-group, presentation, and classroom activities. This use of multiple media and tools for communication and construction ensures all students have access to learning opportunities – no matter their specific location or situation.

Student engineers also have several opportunities to practice communicating technical and non-technical topics to a variety of audiences using multiple media. For example, students present an IRE Talk, which is a TED-like talk on a topic of their choice, to faculty, staff, and peers to receive positive affirmations and areas for growth in their public speaking skills. They will continue to give IRE Talks in each subsequent semester to build upon their previous experience. Another example is the opportunity for students to present their design project. They do a presentation after each of the three segments of their project to faculty, staff, and other students in preparation for their final presentation to their client.

To facilitate and scaffold these activities, students are connected with a variety of faculty and staff members who help them develop their skills. Ph.D. professors facilitate technical learning while preparing student engineers to become life-long self-directed learners. Engineering professionals, which are referred to as program facilitators, from various engineering industries and other staff members facilitate most of the design and professional learning. These connections with professors and facilitators allow students to build fluencies with graduated levels of support for practice and performance. Learning can be more heavily scaffolded and supported by faculty and staff at the beginning of the BA, and these scaffolds can be gradually removed as students continue to grow and develop.

Each student engineer is assigned a program facilitator to serve as a learning coach to work one-on-one with. Conversations between the facilitator and student take place on a weekly basis in the BA to discuss the progress of short-term and long-term goals with relation to personal, technical, design, and professional realms. These meetings serve as a space for supporting planning and strategy development that is meaningful and relevant to the student’s learning.

Additionally, each student is assigned a learning journal reflection to write about an experience or area of development. The written reflections become an open dialogue between the learning coach and student engineer and a way to enhance student capacity for monitoring progress. Pluskwik et al. (2022) discuss the power of reflection and how it is practiced at IRE. They also highlight the benefits of the written documentation, which serves as evidence of student development, sparking conversation for continuous improvement within the program.

7 RESULTS & DISCUSSION

As described in the Methodology section, the results are reported in the form of a discussion of the approachable recommendations for implementation. The BA itself serves as a one-semester bridge program, but the components of UDL practiced in the academy to develop student engineers can be implemented in a variety of educational spaces including first year introductory programs, capstone experiences, and even in individual technical courses. There are pieces that can be implemented without an entire curriculum or program overhaul.

Reflection is one of the simplest implementations that can be integrated in a variety of ways. Allowing students space to reflect on their learning and growth will encourage their motivation and increase their ability to be responsible and self-aware student engineers. Reflections can be integrated as whole assignments, such as a learning journal, but can also be placed within other assignments, such as in student's notes, exit tickets, self-assessment, etc.

Career development is an effort that can and must be integrated within courses or programs at large. It cannot be expected that these developments will automatically happen. While some students may take advantage of a career center or workshops offered, in order to equitably prepare all students to thrive in their future workplaces, efforts must be intentionally included and required in classes and/or programs.

Existing capstone design projects in programs leave space for **just-in-time professional learning** in the realms of teamwork, conflict management, design strategies, etc. that can happen coupled with the project time. Many programs simply let students work it out, but there can be intentional learning and teaching efforts to help students improve their skills before entering industry.

8 LIMITATIONS & FUTURE WORK

This study was conducted by faculty and staff directly within or closely involved with the workings and purpose of BA. This perspective focused more on the design and implementation of the BA and its alignment with evidence-based teaching, which is much more logistical facing. As such, in the future, we would like to study student outcomes and perspectives of their BA experience when contrasted to traditional engineering programs. Employer perspectives also warrant a study to determine if the BA is succeeding in helping students be more prepared for industry placements.

9 CONCLUSION

Ultimately, the goal of the BA is to create a space where engineering students from all backgrounds are able to develop and practice the skills they need to become student engineers. The contrasting language between "engineering student" and "student engineer" illustrates the growth that occurs in the BA; rather than developing engineering students who are competent in textbook problems, the BA develops student engineers who are competent in technical, design, and professional skills. Integration of all aspects of learning is crucial to building the whole student. Engineering education cannot solely be focused on technical learning; real people need flexibility and support in the preparation to thrive in industry placements. The bridge-type style of the one-semester BA allows students to connect, adapt, and grow to an ever-changing world. This overall transformation allows them to thrive in their industry placements, which is evidenced by an industry partner who said, "IRE's new approach to education creates opportunities for talented individuals in a way that allows them to find and pursue their best. At IRE, they are not only creating value for their students, but they are also getting it right for industry. These are the types of initiatives that help shape our future."

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A SCOPING REVIEW OF EXAMPLES ON MISSION-DRIVEN AND MISSION-ORIENTED INNOVATION IN ENGINEERING EDUCATION RESEARCH

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ABSTRACT

Engineers of the future are being requested to become part of solutions for dealing with complexities in the world, exemplified by the adaptation of the 17 United Nations sustainable development goals (SDGs). Ensuring that engineering students are introduced to these is of the utmost importance, if sustainable solutions to grand challenges shall be developed, whether being of technological, social and cultural, and/or economic character. This paper entails a scoping review of the concept of mission-driven or mission-oriented innovation, as defined by the European Commission (EC) and the Organization for Economic Co-operation and Development (OECD), in engineering education research (EER). Seven papers were identified as relevant out of 50 papers derived from five databases, which were then reviewed by the two authors, indicating a substantial gap within engineering education research of mission-driven initiatives in education and research. It further reveals significant overlapping understandings, as the papers included often align their focuses with the SDGs without relating them to mission-driven or mission-oriented conceptual understandings. Outcomes of this scoping review propose that the field of EER acknowledges possible affordances, albeit challenges are still present, for engineering students in applying missions as a binding component for framing projects, cross-disciplinary collaboration, and partnerships with companies, authorities, or other stakeholders. Finally, future research directions are suggested in the field of EER with regards to mission-driven or mission-oriented innovation for grasping practical circumstances for staff and students involved in the works of dealing with complexities through missions.

1. INTRODUCTION

Since 2015, by the adoption of The United Nations Sustainable Development Goals (SDGs), member states of the UN have agreed to commit in seeking solutions for 17 overarching goals (The UN, 2016). This event has sparked shared support across international organizations and institutions as seen with The European Union (The EU) or The United States Government (The EU, 2023; NSB, 2020; Mazzucato et al., 2021). Foreseeing future impacts of global character for accommodating activities, strategies, or policies to solve the 17 SDGs is by default not achieved individually, as it requires multiple societal stakeholders to engage in collaboration to co-create innovate and sustainable solutions. A proposed framework concerning mission-driven and mission-oriented innovation policy (MOIP) has since emerged, which entails specific approaches for solving grand challenges related to the SDGs (Mazzucato, 2017; Purcell et al., 2019). Universities, nation states, the private and civil sectors are all requested to become involved across domains in solving specific missions and developing project-portfolios that can lead to innovative solutions for overcoming societal challenges (ibid).

Research and education are two pillars that shall contribute to positive changes, and herein are engineers a vital part (McQuarrie, 2022). Engineers have historically been involved in the transformation of societies dating back to the ancient civilizations of Greece and Egypt, and a great amount of the seven wonders of the world was designed by engineers (ICEE, 2021). Same needs can be transferred to settings of today, wherein engineering as an ability is required in the formation of solutions to the SDGs. In this matter, engineering education research (EER) plays a vital role in educating students that possesses skills and competencies to fulfil the UN's 2030 agenda (McQuarrie, 2022; Van den Beemt et al., 2020). However, since mission-oriented initiatives and grand societal challenges are complex entities, research and education cannot stand alone (Mazzucato, 2018; Wanzenböck et al., 2020). Both the civil society, policymakers, the private markets, and multiple governments have stakes in the sustainability agenda. In a political orientation, mission-driven and mission-oriented innovation is seen as pathways for decisions of economic nature (ibid.). Mazzucato and Wanzenböck et al. draws parallels to historical missions, such as the Manhattan project or the Apollo missions, that led to innovation in the stream of uncertainty and economical and technological advancements, producing both political and economic value (Ibid.). Today, even though no formal definition is developed by the OECD, there are found traces of what missions' entail: 1) directed, 2) challenge-oriented, and 3) boundary breaking (Wohlert et al., 2021). When perceiving mission-oriented innovation in settings of academia and higher education, the concept seems to consist of all the characteristics but seem to avoid politization when setting goals for mission-challenges. Research is a component in the processes occurring alongside the political sphere, although, abiding to strategies from both supranational and national levels (EUA, 2018). Arguments for the purpose of research and education institutions in this matter are found to be aligned with economic rationales, but perhaps as important is the transformative and innovative potentials of benefiting societies of the world (EC, 2019).

Engineers can be contributors to both factors, but questions arise concerning what engineering educations across the globe have initiated since 2015 in undertaking missions as core concepts of strategic relevance, and whether endeavours are found existing in literature pertaining to higher education institutions? Mission-oriented and mission-driven are terms that has undergone changes in understanding throughout recent times, as in systemic public policies (big science to meet big problems) or as in a contemporary setting to address grand societal challenges. The key differences can be said to relate to an element of time and endurance (Mazzucato, 2017). As of writing, there is not a large sum of universities worldwide that actively has sought to implement mission-orientation as their key argument in educational strategies. Whether it is due to political influences or intrinsic motivation is not the purpose of this study.

1.2 Purpose of the study and research question

Recent literature has echoed the gaps in the context of universities' adaptation of SDGs as core drivers for educational strategies potential partnerships for collaboration (Purcell et al., 2019; Chankseliani & McCowan, 2021). Suggestions are prescribed for establishing conceptualizations and frameworks to be applied, that can bring forth possibilities of facilitation of missions and mission-projects without constraining the dynamics of the respective institutions (Chankseliani & McCowan, 2021; HESI, 2021). The field of higher education has since 2015 seen a rise in research pertaining to SDGs, in some cases aligned with the concept 'third mission of universities' (Neary & Osborne, 2018), but it appears that the trend of mission-driven and mission-oriented innovation has yet to reach EER. If engineering students and researchers across the globe should play a vital role in these perspectives, additional emphasis should be advocated for in the field of EER, which this paper addresses with mission-driven and mission-oriented concepts as its point of focus.

This paper is a response to the scarlessly available research within EER related to mission-driven and mission-oriented strategies or experiments. Integration of formalized practices based on theoretical and conceptual understandings are being requested by the European Commission (EC, 2018), but as no strict decisions have emerged on how to incorporate missions as the steering drivers for engineering students or researchers, it presumably becomes detached from actual teaching, study, or research practices. Suggestions for initiatives can, although, be found in common European agendas of higher education relevance, as exemplified by the European University Association's 2026-agenda (EUA, 2023). Furthermore, as mission-driven and mission-oriented practices and proposals are created through political negations and strategic decisions, it is difficult to grasp circumstances for engineering students and researchers. To achieve a better understanding of what mission-driven- and mission-oriented strategies and related practices entail in engineering education, a scoping review is conducted to present current characteristics found in research revolving around these concepts.

The driving research question for this study is as follows: *What characterizes mission-driven innovation, mission-driven strategies, or mission-driven policies in engineering education research?*

2. METHODOLOGY

2.1 Protocol

As a guiding methodological framework, Arksey and O'Malley's framework for scoping reviews is applied since it is referred to as the acknowledged standard when undertaking scoping reviews (Levac et al., 2010; Pham et al., 2014; Tricco et al., 2016; Denton & Borrego, 2021). It consists of five stages: 1) Identifying the research question, 2) Identifying relevant studies, 3) Study selection, 4) Charting the data, and 5) Collating, summarizing, and reporting the results (Arksey & O'Malley, 2005).

The search queries for this study were completed in February 2023, in five databases: Scopus, EBSCOhost, Engineering Village, ProQuest and Web of Science. This was done for a thorough and holistic representation to be present, which emanated in several searches in multiple databases for documentation to increase the reliability of the findings (Denton & Borrego, 2021). The search did not include unpublished records, instead snowballing searches was done in Google (google.com and Google Scholar) to capture relevant studies not included or published in journals and conferences. An outcome was the discovery of review papers, strategic documents and funding information related to mission-driven or mission-oriented innovation (none of which had been through peer-review). Although, it did not bring forth relevance for engineering education, it was used to identify and cross-reference potential search words. The final search involved key search terms and to avoid limiting the potential results, it was intended to be broad in contrast to systematic literature reviews (Tricco et al., 2016).

(mission-driven OR mission AND driven OR mission-oriented OR mission AND oriented OR mission AND oriented) AND Engineer* AND Education* AND Sustain*

Figure 1 – Search terms applied

This scoping review does not entail a general overview of the state of MOIP as a concept, instead a solitary focus is placed on the terms mission-driven and mission-oriented innovation, which are used interchangeably for the purpose of this review, as the generic understanding applies to both terms (Wohlert et al., 2021).

2.2 Eligibly criteria

For this study, papers of all types were included in the initial screening of abstracts, however, to identify relevant studies limiters were applied based on following criteria: *year of publishing between 2015-2023, English Language*, *a Higher Education context*, *Engineering Education* or Similar wordings, *Sustainability* (or *SDGs*). The timeframe is set to entail publications after the adaptation of the SDGs by The European Union (2015), and the publications were required to involve *engineering education*.

2.3 Selection process

As scoping reviews can be defined as "a *type of research synthesis that aims to 'map the literature on a particular topic or research areas and provide the opportunity to identify key concepts; gaps in the research; and types and sources of evidence to* *inform practice"* (Pham et al., 2014), the readings of abstracts and full texts was mainly linked to the latter of informing practice and to demonstrate gaps in research. Considering the novelty of mission-driven and mission-oriented innovation in EER, the purpose is to understand the context and degree of prior research. The apparentness in how limited the research on the topic of mission-driven and mission-oriented is, can be exemplified by the relatively small number of results (N=74), which made the main reviewer omit the screening of titles, instead abstracts were read for the entire pool. The screening process was also characterized by inclusion and exclusion criteria being developed post hoc, as the increasing familiarity of literature provided leeway for determining relevance (Arksey & O'Malley, 2005). In the phase of screening full texts (N=13), four reviewers independently read the papers to filter out potential redundant articles, generate preliminary codes, and to determine the relevance for the research question. This was done in accordance with inclusion criteria from the main reviewer, which the review-team was presented before coding. A meeting was subsequently held by the review-team after the coding phase, to align findings and reiterate any opposing understandings, resulting in adjustments of codes and extracts for final included papers (N=7). It should be stressed, that for a certain degree of validity to exist, at least two or more reviewers should read, confer, and reiterate findings in any type of literature review. A summarized description can be seen in the flowchart below (Fig. 1).

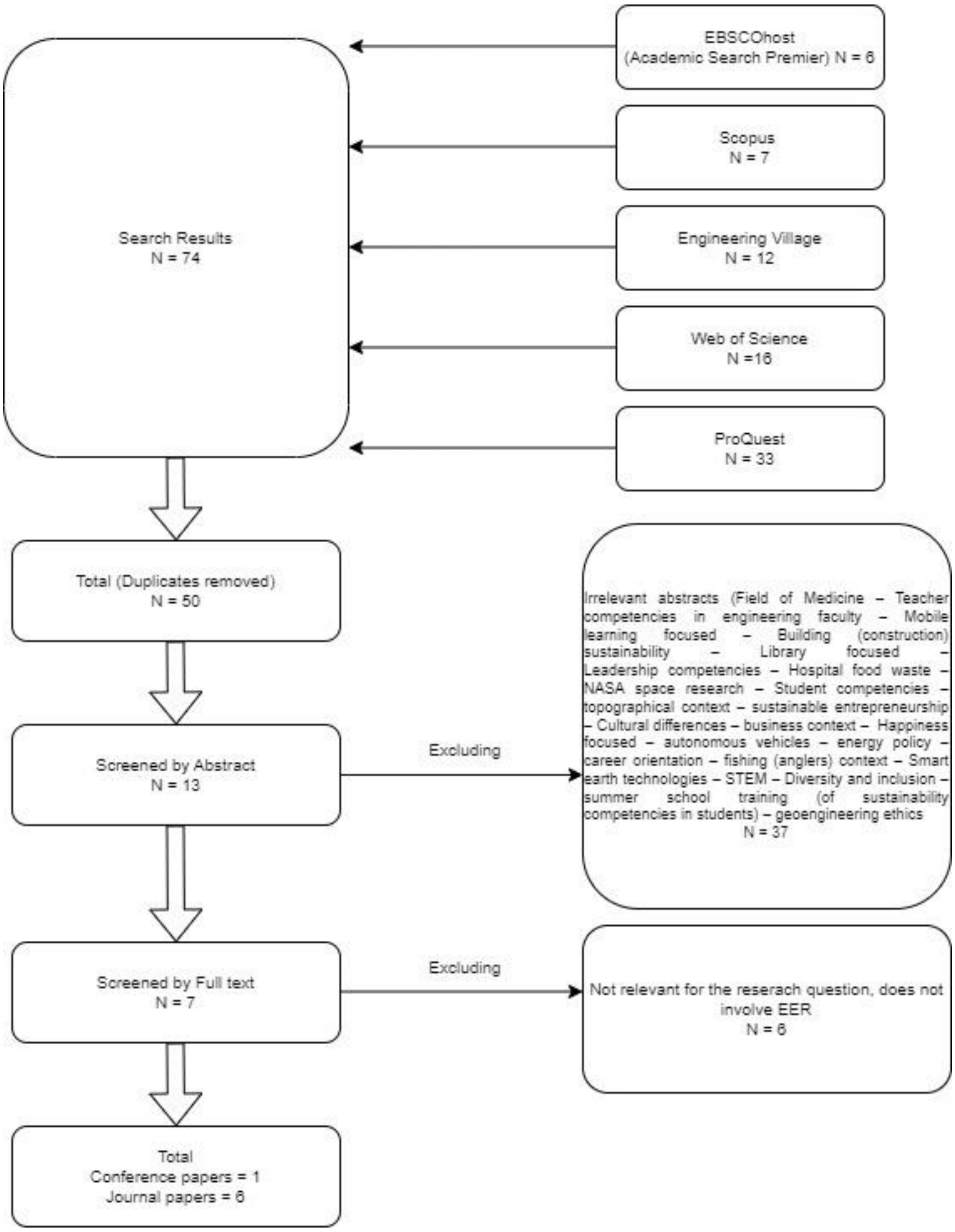

Figure 2 – Flowchart of the scoping process

3. Findings

Based on the charted data derived from extracts from the coding phase, the following section will present the outcomes found. A thematic inspired analysis, for summarizing information aligned with the research question, has been applied for the reporting of findings. These have, as Levac et al. (2010) suggest, a resemblance of similar qualitative analytical techniques which is not explicitly clear in Arksey & O'Malley's (2005) framework. The findings are organized based on three dominant categories: *Mission-driven and mission-oriented indicators*, *strategies and political processes*, and *innovation*. These have constituted the main theme of *characteristics in mission-*

oriented and mission-driven activities, processes, or projects in EER, which have led to three analytical themes: *Framing innovation, Strategic and political arguments*, and *Processes of mission-driven and mission-oriented innovation in EER*. It should be disclaimed that due the minimal appearances of mission-driven or mission-oriented framing or application at an institutional level in the seven articles, SDGs was also included during the coding phase, but without explicitly being used as a term for the search string. Again, this demonstrates the meagre focus on mission-driven and mission-oriented initiatives in EER, contrasting the commonly applied related framing aligned with SDGs (which are plentiful in research – as well in EER).

3.1 Summarization of papers

Table 1 present an overview of the articles included for this scoping review of mission-driven and mission-oriented innovation initiatives at engineering educations that exists in literature. However, as the final pool consist of a scarce and limited number of articles, this scoping review arguably functions as an indicator for the novelty of mission-driven proclamations in engineering education. The articles have been mapped according to year of publication, theoretical indicators, applied methods, whether they mention or relate to the SDGs or mission-driven and mission-oriented innovation, and whether empirical data is included, which they build their work upon.

In general, the generic information from the pool of articles resemblance the novelty of the concepts but also highlights that mission-driven and mission-oriented aspects and activities are few (almost non-existing) in engineering education. Combined with the notion of a minor use of empirical data, it showed that only 2 out of 7 articles build their arguments on empirical data.

Concerning the articles depicted use of methods, case-studies were most frequent (N=3) with interviews the second most frequent (N=2). It opens for question related to the general tendency that are common among all seven articles, which is whether the research objectives are placed on students, the organization, or research projects in a mission-driven and mission-oriented framing.

It appears to reflect the same tendencies as choices of methods when perceiving theoretical indicators, since theoretical arguments and explanations most often concern either a specific research project or student contexts. Enquiry-based or problem-based learning are found applied in 2 of the 7 articles but like categories of empirical data inclusion or method indicators, theoretical representations is also omitted in certain examples (N=2). System thinking and organizational theory both appear in one article each, arguably either concerning the institutional structures for mission-driven transformations into research or education or specific ways of framing sustainability at universities undertaking aspects mirroring mission-driven conceptualizations.

When perceiving how the articles depict their framing of core concepts as drivers for their research, both SDGs and mission-driven and mission-oriented terms are found applied. In mission-driven and mission-oriented innovation frameworks, such as

Mazzucato's (Mazzucato, 2017), it explicitly pertains to sustainable solutions – in a general sense according to the 17 SDGs. Articles included in this study either frame their context according to one of these or both. Most common in the content and purpose of the articles is SDGs as a main argument (N=5), indicating that authors acknowledge the importance of SDGs for constructing and steering their research. It is however, also commonly found that the concepts of mission-oriented or mission-driven innovation appear in similar frequency (N=4). What is quite interesting is how often articles present both terms consecutively (N=2). This indicates that the general framing accords to the 17 SDGs but simultaneously adheres to a specific understanding of dealing with the SDGs.

As no concrete requirements are placed upon the specific approaches for the processes of scaling grand challenges of society and the designs for dealing with missions (Mazzucato, 2017; 2018), it is, as described by Wanzenböck et al., likely due to the aspect of *growth* implicit in mission-driven innovation conceptualizations (EC, 2018). As missions are to be tackled in collaboration across sectors, divergent and convergent views on problems might be in risk of affecting the problem-solution space (Ibid.), and as described by the Global Research Council, missions shall be economically feasible, which can further hinder the aim for decentralized partnerships (UK Research & Innovation, 2019).

Paper ID	Author(s), year, title, DOI / ISSN	Publisher	Theoretical perspectives	Methods applied	Mentions mission-driven and mission-oriented or SDGs	Empirical data (if available)
[a]	Aguilar, A., Wohlgemuth, R., & Twardowski, T. (2018). Perspectives on bioeconomy, https://doi.org/10.1016/j.nbt.2017.06.012	Journal: New Biotechnology 40 (2018) 181–184	N/A	N/A	Mission-driven	N/A
[b]	Willicks, F., Varney, V., & Haberstroh, M. (2018). Board 97: Sustainable Development Goals Meet “Third Mission”: The Engineers Without Borders Challenge in Germany. https://doi.org/10.18260/1-2--30147	Conference: ASEE 2018	Problem-based learning (PBL	Solution concepts	Both mission-driven and SDGs	Two-part evaluation – standardized questionnaire (pre-and post-evaluation)
[c]	M. Jütting, "Crafting Mission-Oriented Innovation Ecosystems: Strategic Levers for Directing Collaborative Innovation Toward the Grand Challenges,", doi: 10.1109/TEM.2022.3171735.	Journal: IEEE Transactions on Engineering Management	N/A	Multiple case-studies (cross-case), document analysis, semi-structured interviews	Mission-driven	N/A
[d]	Mihály, S., Remetey-Fülöpp, G., Kristóf, D., Czinkóczky, A., Palya, T., Pásztor, L., Rudan, P., Szabó, G., & Zentai, L. (2021). Earth observation and geospatial big data management and engagement of stakeholders in Hungary to support the SDGs. doi.org/10.1080/20964471.2021.1940733	Journal: Big Earth Data 2021, VOL. 5, NO. 3, 306–351	N/A	Status review (related to Earth observation (EO) and geospatial data (GI)), case study	SDGs	N/A
[e]	JM Serna, TS Chaparro, WM Purcell, CM Aldeanueva (2022). Driving Transformational Sustainability in a University through Structural and Academic Innovation: A Case Study of a Public University in Spain, EISSN-1941-1766	Journal: Advances in Engineering Education 2022: Volume 10 Issue 1	Organizational theory	Case study	SDGs	Student surveys. Student employability follow up. Periodic academic commissions. Official quality assurance procedures applied by the Spanish higher education authority. Outputs of partnerships.
[f]	Randles, S., Dewick, P., Hannan, E., Nicholson, D. T., Rietbergen, M., Taylor, C., Vargas, V. R., Wadham, H., & Withycombe Keeler, L. (2022). Applying enquiry and problem based learning to mission-oriented innovation policy: From policy to pedagogy to teaching and learning practice. doi.org/10.1108/JIEB-04-2021-0046	Journal of International Education in Business, 15 (1). pp. 52-73	EPBL based on Problem-based learning (PBL), Enquiry-based learning (EBL)	Systematic literature review, in-situ experiments, researchers own subjective experiences, design workshops	Mission-oriented innovation	N/A
[g]	Riekki, J., & Mammela, A. (2021). Research and Education Towards Smart and Sustainable World. doi.org/10.1109/ACCESS.2021.3069902	Journal: IEEE Access	System-thinking	N/A	Both mission-driven and SDGs	N/A

Table 1 – Overview of the papers included (with Paper IDs as points of reference)

3.2 Mission-driven characteristics in EER

The included articles for this study generally entail framings that peripherally mention mission-driven or mission-oriented innovation (or research and education) and SDGs to argue for the relevance of including the concepts in research or education in engineering educational contexts. Through the coding and thematic categorization, findings concern the characterization of mission-driven and mission-oriented concepts, as differences was found related to both on which levels and in which situations these concepts occur. It further seeks to encapsulate what the research question aims to uncover in explicating EER and examples of mission-driven and mission-oriented across published research. It should be noted that the novelty of mission-driven activities and processes in EER affected the thematic representation– therefore, an article is necessarily not applied in each analytical theme.

3.2.1 Framing innovation

In engineering education specific contexts, mission-oriented and mission-driven representations range from sporadic and minor involvement to explicit and concrete uses of mission-driven frameworks or conceptual understandings. In here, a strong buzzword appearing is *innovation*. In paper [a], innovation is applied as an urgent aspect for research projects working towards a stronger bridging of science and technology in a bio-economical perspective. They argue that support is needed to facilitate and sustain mission-oriented research by long-term commitment from industry and society and without it, innovation will cease to exist. Paper [f] frames innovation as a process that is bound to transform how institutions engages global issues that differs from previous technology-pushing solutions. The authors argue that pillar 2 in the Horizon Europe program is a direct framing of mission-oriented innovation policy for research institutions in the respective member states shall address system transformation in conjunction. Another framing of missions at an institutional level is found in the paper by [d], pointing towards a political dimension, as no grand challenge or mission-projects will suffice if not all relevant stakeholders, including governments and politicians, are collaborating internationally – both concerning research and decision-making.

3.2.2 Strategic and political arguments

The articles included do all, to various degrees, frame mission-driven and mission-oriented innovation in engineering education as being rooted in strategies and political processes. Differences are found to refer to either the purpose of research including both engineering and non-engineering disciplines, the financial support needed from governments or businesses, or trans- and international collaboration through initiatives from supranational institutions. Most frequent, when perceiving politics and strategies in EER concerning mission-driven and mission-oriented innovation, is the association made between funding, e.g., from the European Union, and the possibility to design and enact on missions and mission-projects (N=4). It can be, as [f] or [g] portrays, in the argumentation for choosing mission-driven research campaigns where politics and strategies appear, often related to specific supranational education and research initiatives such as Horizon Europe. Paper [d] describes, that the management of earth observation and geospatial big data require national partnerships with similar peers but also support from the Hungarian government and international alliances, although not involving missions but instead SDGs. The cross-case analysis produced by [c] explores how collaborative innovation was conceptualized by studying 15 mission-oriented ecosystems in Germany and found that the most important stakeholders to involve in mission-oriented innovation collaborations was politicians and political processes. If the presence of these were missing, financial support to the collaborative ecosystems would potentially cease to exist. Politics was also found to be directly linked to the prompting and scaling of solutions into society – both nationally and globally (Ibid.). An important aspect to consider, is the design of missions, the cross-sector collaborations that involve a mix of authorities, scientist, entrepreneurs, and the civil society, which can be complex and challenging to facilitate if decisions are made top-down [f]. Furthermore, if universities, and herein EER, shall become involved and heard in the process of creating innovation, external stakeholders, such as aforementioned, shall also proactively become engaged with educators that train students in mission-driven and mission-oriented approaches to education (ibid.). Transgressing borders of educational institutions and moving beyond internal structures of universities, is what [e] describes as a necessity for dealing with complexities (such as the SDGs) through research and education for generating long-term impact.

3.2.3 Processes of mission-driven and mission-oriented innovation in EER

As mission-oriented and mission-driven innovation in EER are relatively underexplored concepts, programs, courses, or research projects rarely involve concrete and explicit orientation towards existing frameworks. The pool of papers derived are primarily describing efforts and examples in ongoing and finished research, as the papers all are peer-reviewed and therefore work-in-progress and early stages of experimentation are perhaps yet to be submitted or published. The difference is whether research projects apply it into practice (N=3), or merely include mission-driven and mission-oriented concepts as argumentation for a relevance (N=4), often in conjunction with SDGs as a focal point. One example of a framing according to Mazzucato's mission-oriented innovation policy framework is found in the literature review of synergies between Enquiry- and Problem-based learning (EPBL) and mission-oriented innovation by [f]. They used their findings from the review to experiment in-situ with two undergraduate modules at the Faculty of Science and Engineering and Faculty of Business and Law (Manchester Metropolitan University). In these experiments, mission-oriented innovation and EPBL were constructed and applied in such a way, that both the university and surrounding industries and societal stakeholders was explicitly included in the attempt to establish cross-faculty interactions and inter- and transdisciplinary routines for both staff and students. Paper [c] examined the 15 technology-based ecosystems according to the concepts of mission-oriented innovation and grand challenges. This serves as an example on how ecosystems, wherein stakeholders from all sectors are collaboratively engaged, and both private and public entities support processes of innovation through funding. His proposal to successful eco-systems reflects a notion of bridging solutions across domains and interests, even when divergent perspectives exist. This implies translating grand challenges into missions that *value capture* rather than value creates, meaning even distribution of value among participants and stakeholders. The similarity between mission-oriented innovation and *system-thinking* is explored in paper [g], and their argument is based on the premise that system-thinking involves a holistic and multidisciplinary approach to problem-solving, where the focus is on identifying and addressing the root of problems, rather than just their symptoms. The necessity for interdependent and interconnected relationships between all included components and stakeholders is found in system-thinking, which can be transferred into a mission-oriented innovation understanding. To this, the authors argue, that SDGs and solutions to tackle them, are requiring cross- or interdisciplinary commitment, which makes a system-thinking approach suitable for creating coherent project-portfolios in relation to missions and promoting diverse research cultures (Ibid.).

4. Limitations, discussion, and recommendations

4.1 Limitations

To obtain a satisfactory degree of breadth and feasibility when identifying relevant studies, there have for the purpose of this review been excluded sources of information (e.g., grey literature or theoretical papers) due to the maintaining of comprehensiveness in the scope (Levac et al., 2010). It is acknowledged by the authors of this review, that potentially relevant studies have been in risk of being left out, but it is not an uncommon procedure for engineering education researchers occupied with scoping reviews to do so (Denton & Borrego, 2021). For retaining a concrete area of interest, further limitations arise by the exclusion of papers outside of Higher Education, in lieu, engineering education was selected to showcase the current gaps of mission-driven and mission-oriented research in that exact domain and to limit additional noise. The risk of neglecting valuable sources of information is therefore present, as this review did not seek to explore SDGs in higher education, but preliminary searches demonstrated that these are predominantly found in literature beyond EER and without being aligned with the terms of mission-driven or mission-oriented. In addition, a potential limitation concerning this study is the concepts of mission-oriented and mission-driven innovation in engineering education originated as a political idea and tool, and therefore examples that arise related to research or education across engineering education institutions rarely involve student activities, which also align with the final pool of articles and their expansion of focus to structural and educational political processes.

4.2 Implications for EER in mission-driven and mission-oriented contexts

The purpose of this scoping study was primarily to highlight the novelty and lack of research concerning mission-driven and mission-oriented innovation in EER – as commonly agreed upon in scoping reviews (Pham et al., 2014; Denton & Borrego, 2021). Reasons for why mission-oriented innovation concerning EER are limited, as of writing, is potentially related to the vast and incomprehensible number of stakeholders needed according to e.g., Mazzucato's mission-oriented innovation policy framework. Organizational theory can be used to argue for the intricate, and often complicated, nature of decision-making in organizations. Since mission-driven and mission-oriented innovation in Mazzucato's conceptual framework entails bottom-up processes, there can occur several difficulties related to a horizontal governance structure Bryson et al., 2006). Uneven balances and competing institutional routines and cultures can also prevent holistic and equal partnerships, and lack of commitment by stakeholders, which in return, demotivates and prevents the feeling of ownership (ibid.). Top-down decision-making in mission-oriented and mission-driven initiatives are also in risk of failure (Nutt, 1999). Often, managers or leaders tend to reward successes rather than failures (ibid.). This can potentially be argued for in business contexts that are market-driven, but in situations revolving around innovation through mission-projects, it is a guarantee that some will fail and not produce innovative solutions – but some will succeed (Mazzucato, 2018; EC, 2018). This is, although to a minor degree, also supported by findings of this review, as few examples were found to involve a clear and concrete involvement of mission-driven and mission-oriented concepts. For a deeper comprehension of the element of collaborating across disciplines, institutions, and sectors, a reference is made to Christiansen et al. (2023).

4.3 Recommendations for future research

Based on the findings, recommendations for further research should 1) consider entailing specific aims to uncover and design functioning ways of bottom-up mission innovation, 2) examine how cross-sectoral collaboration and mission-driven innovation in an engineering education context can establish research across sectors and domains with other disciplinary partners, and 3) re-conceptualize mission-driven and mission-oriented frameworks suitable for higher education, and preferably, include multiple voices and understandings in these designs, as the predominant framework currently used, developed by Mazzucato (Mazzucato, 2017; EC, 2018), is a solitary proposal – in some sense, contradicting the presented call for multiple and diverse perspectives.

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Assessment of Different Platforms for Online Virtual Lab Demonstrations

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***Conference Key Areas**: Virtual and Remote education in a post Covid world; Innovative Teaching and Learning Methods.*

***Keywords**: Virtual Reality, constructivist, active learning, online, virtual labs.*

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ABSTRACT

As we move to a more sustainable world, expansion of education is key to the eradication of poverty (SDG1) and societal inequalities (SDG10). Global expansion of tertiary education offers opportunities to deliver Sustainable Development Goals by providing wide access to education in flexible learning environments. However, the quality of education (SDG4) must be maintained and enhanced as it is key to a partnership for the goals (SDG17). While increased learning online can facilitate achievement of these SDGs, there is also a move, within the education sector, to a constructivist approach and a more active learning environment. Interactive virtual learning environments (*e.g.* Virtual Reality) can offer considerable potential in the integration of active learning in an online environment

With this background in mind, the objective of this study was to evaluate the hardware and software resources currently available for effective delivery of remote virtual laboratory learning against nine technical, social and design criteria. At the same time, it is also important to consider sustainability in this evaluation including carbon (SDG13) and ecological footprints (SDG14/15). Hardware options examined were the Computer, Google Cardboard, Meta Quest 2 and Microsoft HoloLens 2, while the software platforms examined were H5P Virtual Tours, 3D Vista Pro, Dynamics 365 Guides and a professionally created VR platform. The main findings were that there is no 'one-size-fits-all' system and each system has its own advantages and disadvantages depending on the resources available at the institution and the type and level of knowledge and/or skill being delivered.

1 INTRODUCTION

1.1 Section 1

Virtual Reality (VR) technology has gained considerable traction in recent years, with applications spanning several industries, including engineering education. One of the most significant advantages of VR-based simulations is that engineering students can learn, practice, experiment, and make mistakes in a virtual environment, without the fear of causing real or physical damage. For example, in engineering, VR-based simulations can be used to train students on how to construct structures and how to test their designs in a formative way with minimal risk to the students. Furthermore, VR simulations can provide a realistic 3D environment, enabling engineering students to explore complex three-dimensional models from different angles and viewpoints, giving them a better understanding of the model's structure, function, and behaviour.

Another advantage of VR is that it can facilitate collaborative learning. This can be particularly beneficial in situations where students are located in different parts of the world from the teacher and where face-to-face interaction is difficult or not possible. This offers opportunities to deliver Sustainable Development Goals (SDGs) and the globalisation of teaching by providing wide access to education in flexible learning environments (SDG10). VR-based simulations can also be accessed remotely, making it easier for students to learn at their own pace, in their own time, and from any location. These simulations can increase student engagement and motivation (di

Lanzo et al. 2020) and can contribute to a higher quality education (SDG4). Additionally, students can learn at their own pace, with the ability to repeat simulations until they understand the concepts fully (di Lanzo et al. 2020; Al-Ansi et al. 2023; Soliman et al. 2021). More broadly, SDGs and sustainability concepts can be effectively incorporated into engineering education using virtual labs. For example, students can learn about renewable energy sources like solar, wind, hydro, and geothermal power in a virtual lab, which mimics real-world situations and difficulties pertaining to the creation, improvement, and management of sustainable energy systems. Finally, it should be noted that while VR does not replace the need for physically interactive labs, VR allows for increased student interaction, within the constraints of resources available (namely, lab time).

In summary, VR can be a significant tool for engineering education. VR-based simulations can provide students with hands-on training, enhance their visualization and spatial understanding skills, facilitate collaborative learning, and be cost-effective and flexible. VR can also increase student engagement and motivation, providing a more immersive and interactive learning experience. With the continued development of VR technology, its role in engineering education is likely to grow in the coming years.

2 METHODOLOGY

With this background in mind, the objective of this study was to evaluate the hardware and software resources currently available for effective delivery of remote virtual laboratory learning against nine assessment criteria, while also considering the impact of these technologies on sustainability. These criteria were identified based on the authors experience with the technology and are listed below:

1) Integration into Learning Management System (Moodle)
2) Integration of software and hardware tools (Cross-platform translation)
3) Immersive experience
4) Level of user interactivity
5) Ability of system to formatively assess and scaffold learning
6) Ease of use
7) Cost (user cost, institutional cost, maintenance cost)
8) Universal Design for Learning
9) Ethical issues (H&S, GDPR, etc).

Following the identification of the criteria, four different hardware platforms (Computer, Google Cardboard, Meta Quest 2 and Microsoft HoloLens 2), and four types of software (H5P Virtual Tours, 3D Vista Pro, MS Dynamics 365 Guides and a professionally created VR platform) were assessed for compatibility. Appropriate combinations (‘systems’) were then shortlisted for further assessment. It should be noted that the list of available VR/MR equipment and the software evaluated is not exhaustive, and this study represents a discrete examination of the potential options which were available to show the potential of VR as an engineering tool. A ‘least-required’ approach was also adopted, whereby if a software or hardware was considered useful on their own and worked across various platforms then they were included individually; on the other hand, if a hardware/software combination was required, then they were evaluated as such. The final systems that were identified for further evaluation were:

a) H5P Virtual Tours (H5P Group AS)
b) 3D Vista Pro (3DVista España S.L.)
c) Microsoft HoloLens with native apps
d) Microsoft HoloLens with Microsoft Dynamics 365 Guides
e) Custom-created VR platform (on Meta Quest 2)

Assessment factors such as ‘immersive experience’ depend on both the hardware and the software platforms and so they need to be assessed together. Therefore, 3D Vista Pro was assessed as a cross-platform system, as was H5P Virtual Tours, whereas, due to limited overlap, Microsoft HoloLens 2, was assessed separately with, and without, 365 Guides integration and the professionally produced platform will be assessed with Meta Quest 2 only, as it is the only hardware on which it runs.

Systems identified were evaluated in a semi-quantitative way by round table discussion of the authors. Dr Clarkin and Dr Obeidi used their first-hand experience of using these devices with student cohorts in conducting the assessment, while Dr Morrissey and Ms Ryan focused on the non-technical and social aspects of the evaluation. Each system (a-e) was assessed against each criterion (1-9) in a semi-quantitative scale from one to five, with one representing a low rating and five representing an excellent rating. A ‘heat map’ was subsequently produced and a percentage score calculated (Table 1).

No student assessment was carried out in this study as this represented a ‘first-step’ in the system evaluation. It is envisaged that a student-centred study will be carried out in the near future to further evaluate the systems.

3 RESULTS

The findings from the initial analysis of different hardware and software combinations are shown in Figure 1. Following a technical analysis based on the nine criteria, a summary table of the findings is shown in Table 1.

Figure 1: Venn Diagram outlining interaction between different hardware and software options, associated costs and traffic light overall ratings.

Table 1: Summary evaluation of the VR systems from 5 (excellent) to 1 (poor)

Assessment Criteria:	H5P Virtual Tours	3D Vista Pro	HoloLens with native apps	HoloLens with MS Dynamics	Custom-created VR platform
Integration into Learning Management System[a]	5	4	1	1	1
Integration of software and hardware tools[b]	3	5	2	2	2
Immersive experience[c]	1	2	3	5	4
Level of user interactivity[d]	1	2	3	5	4
Ability to scaffold learning[e]	3	4	2	4	3
Ease of use[f]	5	4	2	1	1
System Cost[g]	5	4	2	1	1
Universal Design for Learning[h]	3	4	2	3	3
Ethical issues (H&S, GDPR, etc)[i]	5	4	3	3	2
Total Points (out of 45):	**31**	**33**	**20**	**25**	**21**
Percentage (%):	**69%**	**73%**	**44%**	**56%**	**47%**

Integration into our Learning Management System (LMS) (a). HP5 Virtual Tour is already integrated into DCU's learning platform 'Loop', a Moodle platform, and data from quizzing can automatically move into the Moodle gradebook. 3D Vista Pro can be exported as a SCORM package, which can then be uploaded to Moodle. This is useful when quizzing elements are incorporated into the 3D Vista Pro experience. However, many LMS systems have upload limits set by the administrator and where data intensive elements such as 360 videos are incorporated into the 3D Vista Pro experience this may cause issues. Additionally, grading elements do not transfer across systems, so if using the 3D Vista Pro experience on the Meta Quest 2 this will be independent of the LMS and quizzing elements will not automatically transfer. None of the other systems allow for integration in the LMS.

Cross Platform translation (b). As indicated in Figure 1, 3D Vista Pro integrates across several different platforms while H5P Virtual Tours had some, but minimal, cross-platform integration. The other systems were linked to their individual devices but integrated well overall with those device/software combinations.

Immersive experience (c) and Level of User interactivity (d). Both the custom created VR platform and the HoloLens with Microsoft Dynamics 365 Guides performed well under this criterion. Though it is difficult to compare MR with VR, while both are truly immersive, the HoloLens with Microsoft Dynamics 365 Guides, because of the integration with the real environment and movement, is rated slightly higher.

Ability of system to formatively assess and scaffold learning (e). For hands on learning HoloLens with Microsoft Dynamics 365 Guides far outpaces any alternatives but for information-based learning 3D Vista Pro is very useful for more traditional quizzing options. H5P Virtual Tours does provide quizzing options but those options are very limited. Surprisingly, though one can embed 2D video content (e.g. from YouTube) into H5P Virtual Tours, it does not at present allow for integration of 'H5P interactive video' content with embedded quizzing, which would be a considerable advantage to the system.

Ease of use (f) was evaluated predominantly from the instructor's perspective, but where systems are intuitive for the students they will also ease the burden on the instructors and the resources required to run VR/MR sessions. The H5P Virtual Tours are very intuitive for learners and will require next to no instructor intervention. 3D Vista Pro is similar in this regard, with very minimal instructor input requirement, even when students are first time VR/MR users, which is generally assumed. The other modalities will require some time for users new to VR/MR to become familiar, though it is expected that this will reduce with societal adaption of VR/MR technologies in general. As a result, the amount of instructor resources required for these sessions can be considerable and the time required for allocation of these sessions will be longer.

***System costs* (g)** were evaluated with regard to user (student) costs, institutional costs and maintenance costs. H5P Virtual Tours is free on Moodle and so it was rated highly. 3D Vista Pro has a nominal cost for content developer (€499+vat) and no costs for users. However, this assumes that the system is to run on a PC, for which the cost is not included. However, in the future, and in certain developing economies where PCs are less commonplace this may be worth considering in more detail. It should also be noted that '3D Vista Pro hosting' adds considerable ease of use for the instructor, avoiding multiple uploads to multiple devices and making integration with Google Cardboard much easier, but at a cost depending on the amount of data space required.

Both Microsoft HoloLens and associated 365 Guides represent a considerable cost to facilities, costing ~€4,000 per unit of hardware and anywhere between €708-€1,956 per year (Microsoft 2023). Custom developed VR content can be very expensive when outsourced to professional companies (~€15,000-€30,000). However, the reuse of such systems over the years for many students can reduce the cost to a per student basis but headsets (in this case Meta Quest 2) are still required to be purchased on top of this cost, adding ~€499 per headset.

Universal Design for Learning (UDL) (h). All platforms score low in terms of '*choice of assessment instruments'* but 3D Vista Pro, H5P Virtual Tours and HoloLens with Dynamics 365 Guides do provide for assessment instruments, which can be seen as an alternative assessment means. All platforms score low in terms of providing '*different types of media*' but 3D Vista Pro slightly higher due to its ability to be used on multiple devices. HoloLens with 365 Guides is the only platform that can provide a limited opportunity for collaboration. As the platforms and systems develop, the authors are of the opinion that multi-user experiences will become more commonplace, which would be advantageous in terms of adopting UDL principles.

Ethical issues (i) were evaluated with regard to health and safety concerns and GDPR/user data issues. Neither H5P Virtual Tours nor 3D Vista Pro gather personal data or require login in and of themselves. However, Meta Quest 2 used with 3D Vista Pro or the custom VR Platform does require Facebook sign in. HoloLens with Dynamics 365 Guides is designed around data and gathering of employee data for company analysis (*e.g.* optimisation of production lines). For HoloLens and associated software, Microsoft does gather some data and your organisation will also potentially gather data. It is difficult to fully ascertain the level of data risk with Meta Quest 2 but certainly there is lots of concern. The scope of this project did not allow for a full analysis of the management of data across the different systems and associated use or risk of data leaks but this is certainly something that should be considered in by individual institutions in adopting these technologies.

Though this analysis compared and evaluated different VR/MR systems against one another, there is no 'one size fits all' system and each system has its own advantages and disadvantages depending on the resources available at the institution and the type and level of knowledge and/or skill being delivered. To further assist with this evaluation, the VR/MR systems were also evaluated in terms of Bloom's taxonomy (Figure 2). The 3D Vista Pro and H5P Virtual Tours systems were found to be very flexible and adaptive, easy to use systems but they have limited interactivity and so are best suited to delivering knowledge (Blooms Level 1). The custom developed VR platform in combination with the Meta Quest 2 provides considerably more comprehension capabilities (Blooms Level 2), delivering a more interactive experience but with limited formative assessment capabilities. The HoloLens with Dynamics 365 Guides offers a truly immersive experience that scaffolds user learning in an experiential way and allows them to apply their knowledge (Blooms Level 3) and analyse options (Blooms Level 4); however, the costs can be prohibitive, and use is restricted to a single platform. An ideal scenario would be to provide a multiple systems approach to student training, whereby a simplified introduction to the 360-degree space, with embedded knowledge acquisition is provided by a platform such as 3D Vista Pro. Once complete, students could learn the more interactive requirements of the system using a custom developed VR platform on the Meta Quest 2. Once students are familiar with the requirements to operate the system they can move on to a guided operation with the machine (or machine analogue) using the HoloLens with Dynamics 365 Guides. This will provide a fully automated training system through use of VR/MR platforms. This will provide students with more access to the higher levels of Bloom's Taxonomy (evaluation and synthesis) and future iterations of the systems may allow students to design and test hypotheses and experiments in the virtual world by providing limited branching scenario within the VR/MR platforms, allowing them to better apply and analyse both real world (thorough MR) and virtual (through VR) data.

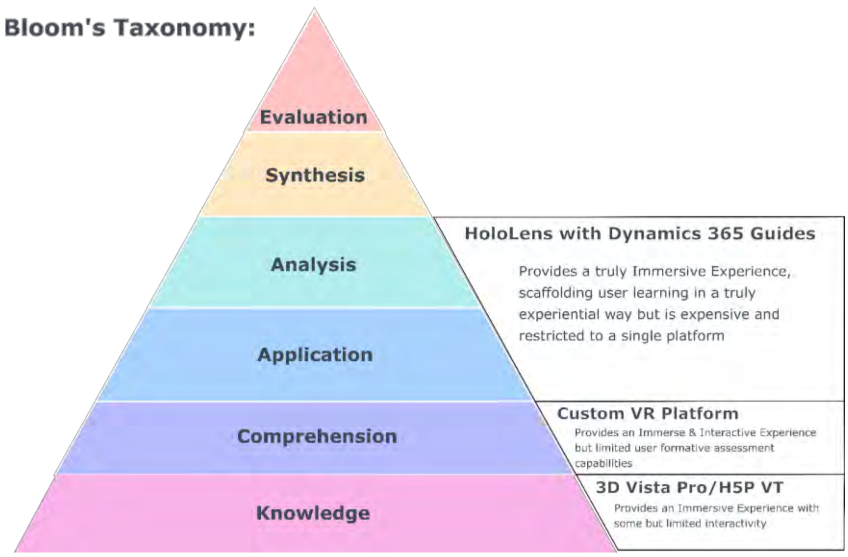

Figure 2: Bloom's Taxonomy Analysis of Three VR/MR Systems

4 SUSTAINABILITY CONSIDERATIONS

Sustainability is a key factor in all industries including engineering virtual reality labs and additive manufacturing as a good example. Below, a summary of some strategies for incorporating sustainability into these fields (Peng et al. 2018; Sandhu et al. 2022, 4-9; Ball et al. 2019, 3-25).

i. **Energy efficiency**: Making sure the used equipment is energy-efficient is a significant approach to encourage sustainability in VR labs. This can be done by adopting energy-saving features like automated shut-off or power-saving modes or by selecting equipment with high energy efficiency ratings (Vo and Huesmann-Odom 2023, 4-9).

ii. **Use of renewable energy sources**: Using renewable energy sources to run the VR lab is another approach to enhance sustainability. In order to lower carbon emissions and energy costs, one option is to produce power using solar or wind energy.

iii. **Recycling and waste reduction**: Unused materials and unsuccessful prints frequently result in a large quantity of waste in additive manufacturing. Utilising recycled materials, improving designs to use less material, and implementing a recycling program for unused materials and unsuccessful prints are all ways to reduce waste and promote sustainability.

iv. **Sustainable material selection**: By choosing sustainable and ecologically friendly materials, additive manufacturing may also be made more sustainable. For instance, using biodegradable materials, it is possible to make items that are both easily biodegradable and environmentally friendly (Reen et al. 2021).

5 CONCLUSION

In conclusion, the integration of virtual reality in engineering education holds immense potential for revolutionising the learning experience. By providing immersive and interactive simulations, fostering spatial understanding, and promoting active learning, VR can enhance students' engagement, comprehension, and practical skills. Addressing the challenges of affordability, technical expertise, and accessibility in line with the SDGs, will be vital in realizing the full benefits of VR technology. With continued research, development, and collaborative efforts between educators, engineers, and VR experts, the future of engineering education stands to benefit greatly from the integration of virtual reality. Each VR/MR System has its own advantages and disadvantages, and educators should choose the combination of hardware and software that best meets the learner needs and learning outcomes required. Providing cross-platform options is also highly recommended where possible, to provide the learner diversity of interactions and cater for diversity of learners.

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THE RELATIONSHIP BETWEEN VOCATIONAL & HIGHER EDUCATION: TIME FOR A RE-CHARGE?

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ABSTRACT

In both the UK and EU there is a growing awareness of the need for Higher and Further Education (HEIs / FEIs) institutions to work together to provide high quality engineering courses able to meet the needs of an increasingly technical and knowledge-based economy (Barrichello et al., 2020, Giraldo, 2022). This paper focuses on learning and teaching in one particular engineering area, that of '*electrification'*, it reflects upon moves to create a regional multi-level educational strategy built upon the development of expertise at partner FEIs.

As one of the UK's leading Engineering Education providers at tertiary level, WMG is leading this boundary-crossing project. An Action Research approach has been developed that transcends organisational competitiveness by creating a multi-level approach to the provision of electrification skills amongst the population of the West Midlands.

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Four different project objectives have been developed:

1. Analyse stakeholder need from the perspective of employers, students and colleges.
2. Analyse extant provision per FEI in terms of physical and human resources
3. Identify any gaps in provision of training available within the region.
4. Develop a plan for the establishment of Centres of Excellence across the region.

This paper discusses the need for synergising provision within what is very much a Quasi Market (Donovan, 2019). It suggests that rather than compete with each other, FEIs need to be working together, and in partnership with HE, create high quality, industry driven and cohesive regional provision. In an emerging field such as ‘electrification’ (of transport and in terms of new battery technologies), the need for regional focus and expert leadership has become increasingly important.

1. INTRODUCTION & BACKGROUND

Following Brexit, longstanding concerns regarding skills shortages in engineering in both the UK and EU has resulted in a growing need for the University, Vocational and Further Educations sectors to work together to provide high quality engineering courses able to meet the needs of an increasingly technical and knowledge-based economy (Barrichello et al., 2020, Giraldo, 2022). This concept paper, which is written at the very early stages of the project, begins by looking at moves by the UK government to begin to address UK engineering skills shortages. It continues by describing how one University, in collaboration with local Further Education providers (Vocational Education & Training), is planning to assure that the F.E. Sector in the West Midlands Region has the capacity to provide sufficient numbers of skilled engineers equipped to work in the ‘electrification’ sector.

One of the keyways in which skills shortages are being addressed within the UK, both in the engineering sector, but also much wider, is through a recent *reinvigoration* of traditional style apprenticeships. Funded through a range of industrial taxes, level three and level four apprenticeships are offered by F.E. colleges, often in partnership with universities. Generally aimed at those over 16 years, apprenticeships provide a direct route into either employment or university. Students study for a level three and or a level four qualification spending most of their time in work.

In the UK. the term apprenticeship represents a formal period of training which lasts between 1 and 5 years, depending on the level of study. There are four levels of apprenticeship, each equivalent to a recognised UK education level; these are:

- Intermediate Apprenticeships (Level 2: Equivalent to GCSE [General Certificate of School Education]).
- Advanced Apprenticeships (Level 3: Equivalent to GCE ‘A’ levels [General Certificate of Education, Advanced]).

- Higher Apprenticeships (Levels 4, 5, 6, and 7: Equivalent to Foundation Degree and above).
- Degree Apprenticeships (Levels 6 and 7: Bachelor's or Master's Degree). **(Gov.UK, 2023)**

Table 1 shows the numbers of students enrolled in STEM apprenticeship programmes over a four-year period (as well as depicting those enrolled in a business, admin and law apprenticeship). It should be noted that it is not possible to access more focused data on gender, ethnicity or previous education of students.

Table 1: Apprentices Enrolled in Engineering & Associated Subjects – 2018/19-2021/22 (Gov.UK.2023a)

Year	**2018/19**		**2019/20**		**2020/21**		**2021/22**	
Subject	*N*	*%**	*N*	*%*	*N*	*%*	*N*	*%*
Business, Administration & Law	118,600	30.2	94,400	29.3	95,900	29.8	93,900	26.9
Construction, Planning & Built Environment	22,500	5.7	21,900	6.8	20,000	6.2	26,100	7.5
Engineering and Manufacturing Technologies	60,000	15.2	52,000	16.1	39,500	12.3	49,100	14
ICT	21,100	5.4	18,200	5.7	18,400	5.7	22,800	6.5
Science & Maths	100	-	200	-	200	-	400	-

** The % Table depicts the percentage of apprentices enrolled in the subject as against the sum of all those enrolled on apprenticeship programmes (when n = 100)*

When considering the need for Further Education to provide skills training for the Engineering Sector, Table 1 reveals a concerning picture, showing that there are twice as many business apprentices as there are those enrolled on engineering and manufacturing courses (Gov.UK, 2023). Furthermore, in the ICT and Construction Sectors the situation is even more dire, with only 6.5% and 7.5% respectively of all student apprentices working and studying in these areas.

Whilst apprenticeships are perceived to be aimed at young people, other training has recently become available for adults. A new government "Skills for Jobs" initiative launched April (2021) aimed to provide adult learners, aged 19 and over, with the opportunity to study for a level 3 qualification in a subject that would equip them with the skills employers' are seeking, thereby enhancing individual job prospects (Dept. of Education, 2021). This initiative provides free training in a number of different areas where there are national skills shortages. It targets those in receipt of unemployment benefit and promises a level 3 qualification and route into employment.

Unfortunately, as detailed in Table 2 below, the success of this initiative is somewhat debatable, although those training in construction, planning and the built environment are twice as likely to succeed than those training within the business area. Interestingly, a cross tabulation of the data revealed a ‘gender attainment gap’ in four of the five areas examined; with male students between 5-16% more likely to succeed and pass the course than female students.

Table 2: Adult Education: Skills for Jobs (Students Aged 19+ Studying Level 3 Engineering & Related Topics at Further Education: 2021 / 2022) (Gov.UK.2023b)

Subject	Enrolments			Successful completions & graduation			Percentage of students succeeding**			M/ F Attainment Gap***
	All	F	M	All	F	M	All	F	M	
Business, Administration & Law	6290	4610	1680	1410	980	430	22%	21%	26%	5%
Construction, Planning & Built Environment	4430	170	4260	1810	50	1760	41%	29%	41%	12%
Engineering and Manufacturing Technologies	2060	170	1890	690	40	659	33%	24%	35%	11%
ICT	2480	910	1570	900	290	610	36%	23%	39%	16%
Science and Maths	230	150	80	30	20	10	13%	13%	13%	0

***The percentage of students succeeding is shown within the subject area.*
****The M/F attainment gap refers to the percentage difference between genders of those who succeed and complete the course.*

Having briefly examined the background of training in the F.E. Sector in the UK, the following paragraphs provide a brief insight into a regional initiative aimed at addressing skills shortages in the engineering electrification sector. It is important to note that the project is very much in it’s infancy. It is acknowledged that there is much work to be done including a wider literature review of the extant literature pertaining to collaborative working between H.E. and F.E.

2. ELECTRIFICATION IN THE WEST MIDLANDS: PROJECT OBJECTIVES

The overarching objective of the project is to prepare the West Midlands Region to react effectively to the changing market demands that electrification is presenting as society moves towards more sustainable technology. The project aims to promote collaborative working between H.E. and F.E. Institutions within the West Midlands. It will ensure that learners are able to access education and training opportunities that will lead to employment, whilst also ensuring that the West Midlands region remains an attractive prospect for inwards investment.

One of the key drivers for the project is the West Midlands Combined Authority (WMCA) which has identified transport and energy as key strategic sectors for the region. This is reflected in the Local Skills Improvement plan. Much of the responsibility for providing education and training will fall on the Further Education sector with c80-

85% of roles requiring training to levels that FE specialise in (this Table is based on the proportion of electrification roles employed with levels of education congruent with FE College delivery. Ensuring that Colleges are prepared to respond to this demand through sufficient capital and operational funding will be critical to the future success of the region.

The project will also drive F.E. Colleges to collaborate more closely with each other together than previously. Whilst numerous previous capital projects have required a level of such collaboration across the F.E. Sector, colleges are necessarily isolationist in a lot of their provision (something which is necessary to maintain competitive advantage within the QUASI market that is the UK F.E. Sector). Taking a regional view exposes the types of skills provision where duplication can readily be supported as the market is big enough.

Colleges West Midlands suggest that at lower levels, college learners are less likely to travel beyond their immediate locality, whilst for more specialist, and higher-level courses, learners are more prepared to travel at further. To avoid future duplication of provision, a wider view needs to be taken to ensure that specialist provision can be accessed with the region. Collaboration across the F.E. Sector will involve the sharing of human and physical resources as well as intellectual property. There is also a need for an institution to take a leadership role, which is where WMG, University of Warwick will step in.

2.1 The 'Market'

Most providers in the region are focused on providing skills for EV servicing. This is in response to the most visible, and clearly defined, need within the current market. However, a wider strategic view of the demands that electrification will bring demonstrates that a focus on the underpinning technologies associated with electrification is also needed. This will enable providers to react more effectively to industrial needs and in doing so expand provision beyond the EV market.

Developing specialisms in batteries, motors, power electronics, robotics and software and hardware engineering, amongst other technologies, will help to secure the region's emerging skills requirements.

3. DISCUSSION: THE CHALLENGES OF COLLABORATIVE WORKING IN WEST MIDLANDS FURTHER EDUCATION SECTOR.

The first phase of the project requires that the WMCA be presented with capital and operational strategic plans to be implemented from the 2023/24 year. The regional approach to capital requests covers a range of different areas such as funding for public engagement and staff. It also identifies four challenges of collaborative working that the project seeks to address. Each of these is now discussed.

3.1 Stakeholder Analysis: What do employers, students, colleges and WMCA want the F.E. Sector to Provide?

Due to their close links with the communities serve, F.E. Colleges are best placed to understand, interpret and react to stakeholder needs. Provision within the F.E. Sector tends to be demand driven and requires a proven market need before courses are made available. However, work undertaken as part of the National Electrification Skills Framework has shown that many employers are not clear about what is required and therefore any skills- needs analysis should look both at the potential for stimulating the market as well as the ability to react to it.

Whilst there is some interest being shown by students themselves in electrification, most young people are unaware of the employment opportunities a career in engineering is likely to offer. To address this there is a need to raise awareness of engineering much earlier in the education journey. One of the key aims of this project will be to establish the means to engage with the Schools Sector, raising awareness of engineering in general and the opportunities training in 'electrification' may bring in particular.

Colleges themselves are key stakeholders in this process and it will be critical to understand the level of engagement they wish to have with a regional strategy. With each college acting as an independent business there are pressures to ensure that they remain individually viable whilst also exploring collaboration. There is precedent for collaboration as seen in requirements for funding which stipulate that bids need to be carried out as part of consortia to limit the dilution of funding. However, where there is duplication of provision there will be natural competition between colleges. This project will take account of this nuanced relationship and identify where duplication of provision, and hence competition, is beneficial to the overall skills landscape. In such cases the project will highlight where collaboration could prove to be the most effective way of ensuring that the region has the educational support and backing it requires.

Finally, the combined authority itself is also a key stakeholder in this initiative. The overall competitiveness, and therefore success in attracting and retaining investment, is critical to the growth of the region. A strong F.E. sector that can provide the skills environment to attract, and retain, employers engaged in electrification will be critical. This stakeholder interest will be realised in the investment provided as a result of the initial report outcomes.

3.2 Identify Extant Provision Per F.E.I. in terms of Physical and Human Resources

There are three key components to this objective, the analysis of current and future planned capital expenditure, the current curriculum, and current human resources. Understanding these in the context of one another, allows for the establishment of current capability and capacity across the region so that planned growth and the ability to deliver against ambition can be realised.

There are a range of physical resources across the region relating to electrification, most of which currently focus on EV servicing and repair. There are also other assets, allowing for delivery of courses to drive capability in other transcendent (e.g., digital) technologies, which are not as immediately apparent. Understanding the extent of physical resource will speak to the current capacity to deliver against electrification competencies. An analysis of current provision will also enable a map of resources to be created to show gaps in coverage that need to be addressed. It is also important to understand planned expansion of facilities as this will inform the potential to grow provision as well as demonstrate capacity growth to WMCA.

Linked to physical resources, is the curriculum. Understanding the scope of provision across the region, as well as planned growth, will enable gaps in academic and skills training provision to be mapped out, and opportunities to be identified for new courses to be developed. Such an analysis will also highlight where employer needs are being met. From the WMCA perspective, understanding the potential capability that will be delivered in the future will allow for speculation around inward investment.

Finally, human resources represent the most critical part of this objective. One of the core driving factors that has influenced the overall strategy is that it has proved to be challenging to ensure that F.E. colleges have the appropriate capability to deliver the required courses. Another challenge represents FEIs' ability to attract, recruit and retain future engineering talent. Without this there is little point in investing in facilities or planning new curriculum. Understanding the status of human resource will enable development plans to be implemented to ensure staff receive appropriate training in line with curriculum growth and that other methods of ensuring that there is sufficient coverage, such as industry secondment, can be explored in conjunction with WMCA.

3.3 Identify Gaps in Training Provision across the Region.

The first two objectives will help to identify current gaps in the provision on offer and enable strategic investment to be made to ensure that facilities, human resources and accredited and approved engineering curricular are in place to meet need. Closing the gap in training provision will also highlight opportunities to attract new investment into the region where the skills environment is present.

The identification of gaps also links closely to analysing where provision can be duplicated and where specialist provision needs to be located. It is suspected that some gaps in provision will be as a result of individual colleges being unable to make a successful business case for the provision of a particular course based on low demand. In these cases, gaps may be closed through collaboration where low numbers can be combined. In addition, there is a case to look at specialisations where colleges who are focused on key technologies will be able to create focal points and close gaps through engagement and collaboration.

Critically, the speed of the way that the electrification landscape is changing means that there will always be gaps opening and closing. The ability of colleges, through their physical and human resources, to adjust and evolve the curriculum will be key in meeting this challenge. When considering capital, and operational, investment there will be a need to engage with organisations, such as the UK Foresighting Hub, to continually look to the future of capability need.

3.4 Develop a Plan for the Establishment of Centres of Excellence Across the Region

When focusing on electrification the decision has been made not to focus on traditional sectors but to focus on enabling technologies. These are termed as transcendent technologies due to their role in transcending the sectors in which they are applied. Whilst sector applications will drive much of the curriculum in the region, e.g., servicing of EV which encompasses a number of the transcendent technologies applied in an automotive context, there is value in having centres that provide focal points in the specific technologies themselves.

In putting the strategy together, the need to establish centres of excellence across the region has become evident. Individual colleges specialising in different skills provision and training need to work together to establish a network of provision purposefully focused on addressing the needs of regional industry. Having such focal points will provide two key advantages. Firstly, where there are gaps in curriculum caused by low student numbers across different providers, centres of excellence can enable viable provision to take place. As such they can address niche requirements across the region in a strategic way bringing students together to study in a particular area. Such centres of excellence will also provide regional leadership in their respective technologies, supporting other providers in areas of best practice.

The 'Centres of Excellence Model' is untested in Further Education and will require further analysis to establish its viability, but there are already examples of providers across the region that could take on this role for specific technology domains. The main challenge likely to be faced in developing the strategy is the willingness of individual F.E.I.s to engage in a collaborative manner to ensure regional success. The idea of Centres of Excellent is, at this moment in time, aspirational but it is envisaged that as the project moves forward the synergetic value that specialisation and collaboration can bring to the region will become a reality.

4. CONCLUDING REMARKS

This brief conceptual paper has set out four challenges faced by West Midlands F.E. Education Sector in developing a strategy for collaborative working so as to meet the future needs in the area of 'electrification'. The role of the WMG, University of Warwick, in this strategy is one of facilitation and leadership, bringing the partners together, writing the WMCA funding bid and acting as a central hub where organisational difficulties and challenges may begin to be addressed.

In conclusion, this project is very much in its early stages. Discussions between the University and local F.E. colleges have promoted a positive response, boding well for the future. Yet much of the detail remains undecided. The presentation accompanying this paper will report on progress, outlining future plans for collaborative working and identifying the challenges faced and overcome. It is anticipated that, by the time of the conference, the regional strategy discussed here will have become a reality. Plans for 'Regional F.E. Centres of Excellence' will hopefully be well underway and many more opportunities will be opening up for next year's cohort of future engineers. Watch this space. The future promises to be exciting!

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The use of Peer Assessment and Group Peer moderation to develop 'soft' skills in Engineering students researching Sustainable Energy

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Conference Key Areas: *Embedding Sustainability and Ethics in the Curriculum; Engineering Skills and Competences, Lifelong Learning for a more sustainable world*
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ABSTRACT

Since the change to an outcomes-based approach in Engineers Ireland's accreditation criteria almost 20 years ago there has been an emphasis placed on 'soft' skills such as teamwork and ensuring graduate engineers are not only well versed in their chosen discipline, but that they can communicate their knowledge – to other Engineers and also non-Engineers. Energy Management is a module taught to 4th year Mechanical Engineers, and the learning outcomes are best assessed by how students can communicate the energy topics they are researching. As an individual they will research an area that interests them and write a paper at the end of semester but leading up to this there are two 'patchwork' assessments from which they receive feedback and can use to formulate the introduction to their final paper. The second of these is peer assessed using the same Rubric as for the first assessment, and they must also review their own writing following this. Feedback has shown that this develops a greater understanding of their writing and what constitutes a good technical writing style. Teamwork is developed in this module through a 35% sustainable energy group project which involves a presentation and a written group report. On completion the students submit a peer moderation form online which allows the grade to be moderated if the work was not evenly shared. The approach taken for each element has evolved over 15 years and will be explored as part of this practice paper.

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1 INTRODUCTION

The importance of communications skills and teamwork for Engineering graduates was emphasised with the introduction of outcomes-based criteria for Accreditation of Engineering programmes in Ireland in 2004, prior to this the criteria to accredit programmes was input-based. Successive updates to the criteria continue to stress the importance of these 'softer skills', with the latest version also introducing outcome criteria around Engineering Management and Sustainability (Engineers Ireland, 2021). It is simply not enough for an engineer to be technically competent; they need to be able to communicate their engineering solutions to other engineers, and also to non-engineers. In 2007 I took over the delivery of a 4th year Mechanical Engineering module – Energy Management. The syllabus covers global and national energy usage and policies, energy and the environment, an introduction to renewable energy, and Combined Heat and Power (CHP). It also covers the thermodynamics behind increasing the efficiency of fossil fuel-based energy production. In the first year, I assessed it as had been done previously, 70% terminal exam and 30% coursework, however it was clear to me that there was a very shallow learning involved in the energy topics, with students typically answering the exam questions with short, bullet like responses. At this time, I was also undertaking an MA in Academic Practice, where I first engaged properly with pedagogy. Biggs (2003) constructive alignment resonated with me, helping me to construct learning by aligning my teaching and developing more active learning to move students away from the tendency to rote learn for terminal exams.

To encourage deeper learning and develop critical understanding and writing skills I endeavoured to change part of the assessment to Patchwork Text to allow for both formative and summative assessment of their ability to write critically (Winter, 2003). This evolution will be detailed in this practice paper, including the incorporation of Peer Assessment of writing as part of the patchwork text. As a practice paper this cannot be generalised for all engineering disciplines, however as writing is a skill relevant to all, the approach is one that can be adapted by other disciplines.

The original coursework involved a group project on a sustainable energy topic. Teamworking skills are valued by employers (and accreditation bodies), so this important element is still part of the module. However, students can have concerns regarding equal workload and effort by team members, and how this affects their grade (Gunning *et al*., 2022). To overcome this group meetings are scaffolded during class time and at the end of the project there is peer moderation of the grades, which will also be discussed. The incorporation of these peer elements is key in developing graduates' responsibility for their own learning, and the evolution of this approach will be outlined in Section 2.

2 METHODOLOGY

It is widely accepted in higher education that assessment plays a large role in student learning (Fischer *et al*., 2023). Assessment for learning is a key feature of my teaching philosophy building on the use of formative assessment with detailed feedback for the students to reflect on (Nicol & MacFarlane-Dick, 2006). The methodology I developed over the years is outined in this section, firstly describing the module assessment, moving from summative to formative assessment (2.1), then looking at this development of formative assessment using patchwork text and peer assessment (2.2), and then use of peer moderation of group project grades (2.3).

2.1 Module Assessment

The module Energy Management is taught in Autumn to 4th year Mechanical Engineers, it is a 15-week semester: 12 teaching weeks, 1 reading week and 2 exam weeks. The initial Assessment involved a 30% group research project on an energy topic, and a 70% terminal assessment, as outlined in Table 1. The second time I taught this module, this was flipped to 70% continuous assessment and 30% Terminal exam. The terminal exam is solely based on the thermodynamics part of the module, using numerical type exam questions.

The continuous assessment included the group research project as before, now focussed on sustainable energy generation, and the introduction of technical writing assignments; the evolution of which will be discussed in Section 2.2. From 2011 to 2018 an in-class or online mid-term assessment was also used, and the Coursework mark increased to 80% with only 20% for the terminal exam. As shown in Table 1, briefly the Terminal exam increased to 30% in 2019, and has returned to 20%, highlighting how I continuously adapt delivery and assessment of the module. During the Pandemic, when teaching moved online, this assessment mode translated well as it already had a small terminal exam component which was then switched to on online exam.

Table 1 Evolution of Assessment mode 2007-2022

Year	**Student Numbers**	**Continuous Assessment**				**Terminal Exam**
		Group Project	Short Reviews	Final Review	In-class or online MCQ	
2007	74	30%				70%
2010	32	30%	10% (5x2%)	30%		30%
2011	46	30%	15% (3x5%)	30%	5% in-class	20%
2012	46	30%	15% (3x5%)	30%	5% in-class	20%
2014	46	30%	15% (3x5%)	30%	5% in-class	20%
2015	48	30%	15% (3x5%)	30%	5% in-class	20%
2016†	42	30%	15% (3x5%)	30%	5% online	20%
2018	67	30%	10% (2x5%)	30%	10% online	20%
2019	74	30%	15% (2x5%) +5% Peer	25%		30%
2020	68	35%	15% (2x5%) +5%Peer	30%		20% (online)
2021	69	35%	15% (2x5%) +5%Peer	30%		20% (online)
2022	74	35%	15% (2x5%) +5%Peer	30%		20%

*2008, 2009, 2013 on leave, 2017 seconded to Athena SWAN team
† Rubrics introduced

From 2020 there was a slight increase to the Group project mark, which corresponds with the introduction of Peer moderation (as discussed in Section 2.3), and following a brief increase to 30% terminal exam, the overall distribution of 80% continuous assessment was returned to.

For all the written elements Turnitin Feedback Studio (previously known as Turnitin Grademark) is used to provide feedback. Up to 2015 the students received marks under several headings using a detailed gradings scheme, with Table 2 showing the scheme for the 5% Short Technical Review. From 2016 this was developed into a set of rubrics for each element (Short Review, Final Review, Group report). This helps scaffold the students' preparation for the given element. Table 3 presents the current rubric for the Short Technical Review, with the marks awarded similar to those presented in Table 2.

Table 2 2015 Grading scheme for Short Technical review (5% but marked out of 20)

	Excellent	Good	Acceptable	Poor	Dreadful
Language style (technical, not colloquial, no rhetorical questions, punctuation, spelling)	4	3	2	1	0
Technical Content	8	6	4	2	0
Introduction, Conclusion (each)	3	2	1.5	1	0
Referencing	2	1.5	1	0.5	0

Table 3 2022 Rubic for Short Technical Review

	Exceptional	Good	Acceptable	Poor	Inadequate
Introduction	Excellent context given Argument/Case to be made is clearly 'signposted'	Good context given Argument/Case to be made is 'signposted'	Acceptable context given Argument/Case to be made is somewhat apparent; Too long/short	Poor context given Argument/Case to be made is not apparent ; Too short	No context provided Argument/Case to be made is not apparent
Language style (technical, not colloquial, no rhetorical questions, punctuation, spelling)	Excellent technical language used, with no colloquialisms, no rhetorical questions. Correct punctuation and spelling throughout	Good technical language used, A *small* number of colloquialisms or rhetorical questions, or punctuation mistakes, or spelling mistakes	Acceptable technical language used; A number of colloquialisms or rhetorical questions, or punctuation mistakes, or spelling mistakes	Poor technical language used; A *significant* number of colloquialisms or rhetorical questions, or punctuation mistakes, or spelling mistakes	Language used is not appropriate for technical report
Technical Content	Excellent breadth of content (appropriate for the length). Clear argument made or position outlined. Excellent support provided for the argument made	Good breadth of content (appropriate for the length). Argument made or position outlined is not fully clear *Or* more support required for the argument made	Acceptable breadth of content (appropriate for the length). Argument made or position outlined is not fully clear *And* more support required for the argument made	Poor breadth of content (not appropriate for the length). Argument made or point is unclear *And* more support required for the argument made	No real content. No argument made or position outlined is not fully clear
Conclusion	Excellent conclusion on the review. Appropriate length for the length of the review. Points made are synthesized well into a conclusion, linking back to the argument signposted.	Good conclusion on the review. Appropriate length for the length of the review. Points made are synthesized into a conclusion, and may link back to the argument signposted.	Acceptable conclusion on the review. Maybe too short. Points made are may not be synthesised into a conclusion, and may not link back to the argument signposted.	Poor conclusion on the review. Too short. Points made are not synthesized into a conclusion, *or* not linked back to the argument signposted.	No real conclusion or conclusion missing. Too short
Referencing	References complete and properly laid out.	Some gaps in references but Reference section properly laid out. *Or* References complete but gaps in reference section layout	Some gaps in references and/or reference layout.	Major gaps in references and/or reference layout.	No references or sources identified for information.

2.2 Patchwork Text

In transforming the module's assessment, I wanted to promote deeper engagement with the topics while also giving the students the opportunity to get feedback on their technical writing skills in advance of writing their Final Year Project report. Patchwork text involves a number of smaller assessments that can be 'stitched together' to give a final piece (Akister *et al*., 2003; Winter, 2003). The first time I undertook this in 2010 I had the students write five short essays, approx. 250 words each, for which they received marks (a small 2% max) and more importantly feedback, and they could choose whether to use these as part of their final essay. The grading load involved was too high, so from 2011-2016 this was changed to three 5% pieces. The students submitted their first essay early in semester, this is graded using the rubric and returned to them before they prepare the second one, and same then for the third; with the aim that these short essays, once reworked based on the feedback, would form the Introduction to the final essay.

Due to engineering student resistance to writing 'essays' the assignment was retitled to *Technical Review*, and the expectation is the writing style is that of a Literature Review. Regardless of what it was called, it was clear from the improvement in the quality of work submitted, and grades attained, that student engagement with the topics increased – leading to deeper learning, as also evidenced by Trevelyan and Wilson (2012). The students' ability to think and write critically was scaffolded by the use of the short reviews and the feedback they received, to help them prepare the longer Technical Review. Their appreciation of this approach has been noted in module feedback, and also in end of year feedback to External Examiners. The introduction of rubrics in 2016, as discussed in the last section further aided in the development of these critical writing skills, as they know before they write what is expected at all levels for all categories under which the piece will be graded.

In 2018 the class size increased by over 40% as shown in Table 1, which meant that the grading workload was too onerous again. Initially in 2018 the short reviews were cut from three to two per student. In 2019 to try ease the workload issues, but also to try develop better critical thinking skills in the students, I decided to involve the students in the grading (Moloney *et al*., 2019). Peer assessment has been shown to robust and is supported as a formative method (Double *et al*., 2020).

The practice since 2019 involves the students each anonymously reading and grading two other reviews using the rubric, after which they must do a self-review. A limitation to this approach is that it is dependent on students engaging with the peer-assessment. To encourage them to do this, they get up to 5% for giving these reviews. Better engagement will get the full 5%, and while this may seem like an 'easy' 5%, feedback from the students in module evaluations and in their self-reviews shows that they find it very useful to see exemplars of their peer's writing. From their reflective self-reviews students have indicated that they find the peer-review very useful in helping them understand how to correctly frame a review – from language style to forming a cohesive argument. Students may distrust peer assessment (Planas Lladó *et al*., 2014), so it is imperative to discuss their responsibilities in advance of the peer assessment. The reliability and validity of the peer assessment is monitored to ensure the marks and comments are appropriate.

While this is a relatively smaller cohort, averaging 70 students, Power and Tanner (2023) have suggested peer assessment is appropriate to use with even larger cohorts with suitable use of a Virtual Learning Environment (VLE) to assure anonymity.

2.3 Group Project - Peer moderation

The group research project has been a key assessment tool in this module, since before I started teaching it. Initially each tutorial group had 15 students per hour, and in five project groups of three students they researched an energy topic of interest over the first 3-4 weeks of semester and then over the following weeks they took turns to give a 30 min presentation. In 2007 for many it was their first time giving a formal presentation, which has since changed with curriculum development. The group research project was timed so that the group presentation took place early in the semester in advance of Final Year project Interim presentations. As there were different dates for presenting, each group then had two weeks to submit the written report. As detailed in Section 2.1 from the start Turnitin Grademark has been used to allow detailed feedback on the report. With VLE enhancements regarding group submissions this has become more straightforward in the last five years. These research projects serve to significantly improve their knowledge in a particular area of sustainable energy and also develop their awareness of other topics, though attendance at the presentations.

Overall this structure has worked very well and there have only been a few changes over the years. As noted, the grading workload is quite substantial, and due to increasing class size in 2020 the groups were increased from three to five students to reduce the number of projects to be graded, with 30 students in 2-hours, allowing six groups of five. In 2021 & 2022, instead of being spread from weeks 4-8, more time was given to project scaffolding in the tutorials, with all presentations occurring between Week 7 & 8, and the Final report due for all in Week 9.

There are student and academic concerns regarding group work and ensuring that those who do the work are rewarded accordingly (Gunning *et al*., 2022). Especially in 4th year, students can worry that their grades and final awards will be impacted, yet the ability to work in a team is a key Programme Outcome for Engineer's Ireland accreditation. Initially for this module each group had to declare how the final mark would be allocated, and when the groups were smaller it was easier to distinguish if the group mark needed to be moderated to reflect the individual workloads. With increased numbers in each group, managing these dynamics became more difficult. In 2021 I introduced the use of an individual online form (using MS Forms) based on a small subset of WebPA criteria (Loddington *et al.*; 2009) where each student rates themselves and their group colleagues under five personal effectiveness criteria, as described in Table 4. If work was shared equally amongst the group, then they are asked to choose 'about average for this group' for all, including themself. The scores for each student under each criterion are averaged, and this has led to more robust peer moderation of the group grade. If any group feels the moderation does not fully reflect the workload, then they are free to discuss this, but as of yet there have not been any issues. Again, module feedback has shown that students value this way of being able distinguish those that have do more work to make up for others.

Table 4 Peer moderation of individual effectiveness (adapted from (WebPA, 2019)*)*

Criteria	Description
Co-operation	attendance at meetings, contribution to meetings, carrying out of designated tasks, dealing with problems.
Communication	effectiveness in meetings, clarity of work submitted to the group, negotiation with the group, communication between meetings and providing feedback.
Enthusiasm	motivation, creativity and initiative during the project
Organisation	Self-organisation and the ability to organise others, including planning, setting targets, establishing ground rules and keeping to deadlines.
Contribution	Overall effort put in by an individual during the Project (Weeks 1-9)

3 SUMMARY

The pivot to online teaching and learning in 2020 and 2021 highlighted that terminal assessment is flawed, especially when the assessment is online and not proctored. In the return to on-campus teaching it is important not to lose the best practices of using increased Continuous Assessment. Taking an ‘Assessment for Learning’ approach, a number of different strategies are used in this module.

- The use of Patchwork Text develops the student’s critical writing skills, though use of timely feedback that can then be used to write their final review.
- Including an element of Peer review in this Patchwork Text structure has been shown, through module feedback and student self-review comments, to also accentuate their understanding of good technical writing, as they see other people’s writing (good or bad) and it obliges them to engage with the rubrics that are used for the assessment.
- Acknowledging the concerns that students have with group project work, the use of peer moderation forms allows for them to acknowledge how the workload was shared, and again from student feedback this has been welcomed.

This paper is intended as a practice paper, to show how my practice has evolved and how I attempt to develop deeper learning and utilise peer elements to foster graduates’ responsibility for their own learning. Over the last two years, following the staged return to on-campus teaching there has been a noticeable change to the level of student engagement. Methods such as these – patchwork text and peer assessment, group work and peer moderation – can assist in motivating a responsibility for their own learning. While the methods are not applicable to all, there may be elements that can be adapted for other’s teaching.

A principal factor of my approach is to move away from the standard high stake terminal exam, that is used by many as it is an efficient way to assess. The approaches I have discussed show a way that a Module Leader can sustainably move to more continuous assessment. This is applicable for all engineering studies, not only the ‘softer skills’. A limitation of this study is that the feedback is all based on module feedback and student self-review, therefore further structured research of student perceptions is planned.

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EUNIWELL: MAXIMISING ACADEMIC AND SOCIAL OUTCOMES IN ENGINEERING EDUCATION

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ABSTRACT

The ERASMUS+ European University for Well-Being (EUniWell) alliance's mission aims to resolve the paradox of Europeans' relative prosperity against the global security and sustainability challenge. "Maximising Academic and Social Outcomes in Engineering Education" is a project which interprets this contradiction for engineering

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educators; how to best teach non-technical skills to ensure engineers make the utmost contribution to societal wellbeing? Appreciably, the social outcome for the person who becomes an engineer is positive because the profession is relatively well-paid. Therefore, engineering education is good for social mobility providing the learning environment narrows attainment gaps between disadvantaged and mainstream cohorts. Accordingly, our strategy is to bring together the expertise of the British, French, Italian and Swedish faculties to transfer best practice for professional, business and sustainability skill teaching, while contrasting how their disadvantaged cohorts present. The project has two primary objectives: To understand how partners differ in terms of skill teaching, and how students from disadvantaged backgrounds are accommodated. The paper describes the background and rationale of the project, and its research design and methodology. Although the project is still in progress and data collection is still underway, this paper provides insights and perspectives for engineering educators looking to design similar collaborations to share best practice, while considering engineering identities and their underlying competencies.

1 INTRODUCTION

Engineering is known to have a distinct cultural identity, which encompasses solving well-defined problems through the development of products, processes, and services. This identity is formed throughout the student's period of study. However, if the focus is solely on developing more practical skills, the question arises as to whether the students are developing holistically; What role do other professional skills have in developing students as engineers? It is our position that currently professional skills, such as innovation, enterprise, and creativity; communication and networking; and social, environment, and technical responsibility, are more subjective and subsequently are not taught as well by faculty. As a result, there are negative social outcomes in terms of satisfaction and wellbeing, despite the student successfully meeting any programme's learning outcomes.

The broader EUniWell alliance mission is to resolve the paradox of Europeans' relative levels of prosperity against the global challenges in society they face: health, environment, political instability, and defence. Maximising Academic and Social Outcomes in Engineering Education (MASOEE) interprets this contradiction for the engineering profession as how to best teach the non-technical skills to ensure engineers make their utmost contributions to societal wellbeing. Our strategy is to bring together the expertise of Birmingham, Florence, Linnaeus, and Nantes engineering faculties to share and develop expertise to improve the social outcomes of engineering students.

The cultural identity of professional engineers is often dominated by practical skills. Therefore, a key aim of the project is to explore ways in which we can 'rebalance' the education of engineering students, ensuring that there is as much emphasis on professional skills as there is on practical. The rest of this paper is as follows. Section 2 provides some theoretical background behind the project; section 3 describes the research methodology; section 4 some preliminary results and section 5 a summary.

2 BACKGROUND

Engineering culture has traditionally focused on technical competence, such as the basics of science and mathematics, design, and analysis skills, as well as the use of engineering tools and methods, which produces a ‘traditional technologist’ (Berge, Silfver, and Danielsson 2019). However, as these authors note, most contemporary faculties dealing with the education of engineers have moved away from this narrow focus and towards incorporating other skills such as professional skills, enterprise, and sustainability and ethics. It is because of this shift to a more contemporary approach, that they suggest that three new engineering identities have emerged: ‘Self-made engineer’, ‘Contemporary technologist’, and ‘Responsible engineer’.

‘Social-technical’ dualism (Faulkner 2015) is the separation of ‘technical’ skills and ‘social’ competencies. It can often be reinforced through both the design and delivery of the curriculum and can subsequently lead to a ‘hidden curriculum’ (Tormey et al. 2015), typically comprising separate learning units for skills which are delivered by non-engineering experts. This results in non-technical competencies being duly taught and learned, but not widely thought of as an engineer’s problem, and thus not fully integrated into day-to-day engineering habits. Our project is designed to not only understand both staff and student attitudes to these skills, but also to identify how this hidden curriculum manifests.

The global marketplace in higher education and its neoliberal trends, where students are customers, and where higher education is expected to produce employment-ready graduates, leads to social outcomes in education being considered chiefly through graduate destinations and earning potential (Berg, Huijbens, and Larsen 2016). As engineering is a relatively well-paid profession, the ultimate social outcome of studying engineering and then entering its profession for the individual can be considered net positive. For this reason, engineering education can be a force for social mobility, especially when faculty make a conscious effort to widen access for disadvantaged students. Consequently, once they arrive on campus, the learning environment delivers and equitable education which narrows any attainment gaps between disadvantaged groups and the mainstream cohorts. MASOEE partners have different definitions for what is considered a disadvantaged student in this context, and consequently what interventions they practice to narrow attainment. Therefore, understanding these differences and how students from these backgrounds experience the process of becoming an engineer and the types of intervention that make a difference is a valuable knowledge exchange.

3 METHODOLOGY

3.1 Research questions

Reflecting on this background, we have formulated the following research questions:

- What are the similarities and differences between engineering partners, their student bodies, teaching, programme structures, and institution culture?
- How are the skills currently taught and embedded in programmes? What are student attitudes to learning these? How do we currently define and measure social outcomes?
- Which new approaches can we employ to better teach these skills that deliver better social and academic outcomes?

Fig. 1 provides an overview of the project, illustrating how the different components contribute to developing a comprehensive understanding of the teaching of professional skills within the partner universities, as well as how the partners are widening participation of disadvantaged students, ultimately narrowing any potential attainment gaps. The project is comprised of four 'Work Packages' (WP1, WP2, WP3, and WP4). WP1, WP2, and WP3 are designed to collect data, offering practitioner workshops and general data collection opportunities. WP1 concerns innovation, enterprise, and creativity; WP2 concerns communication and networking; WP3 concerns social, environment, and technical responsibility. WP4 is utilised to co-ordinate overall engineering education research approaches and research questions, as well as general project management.

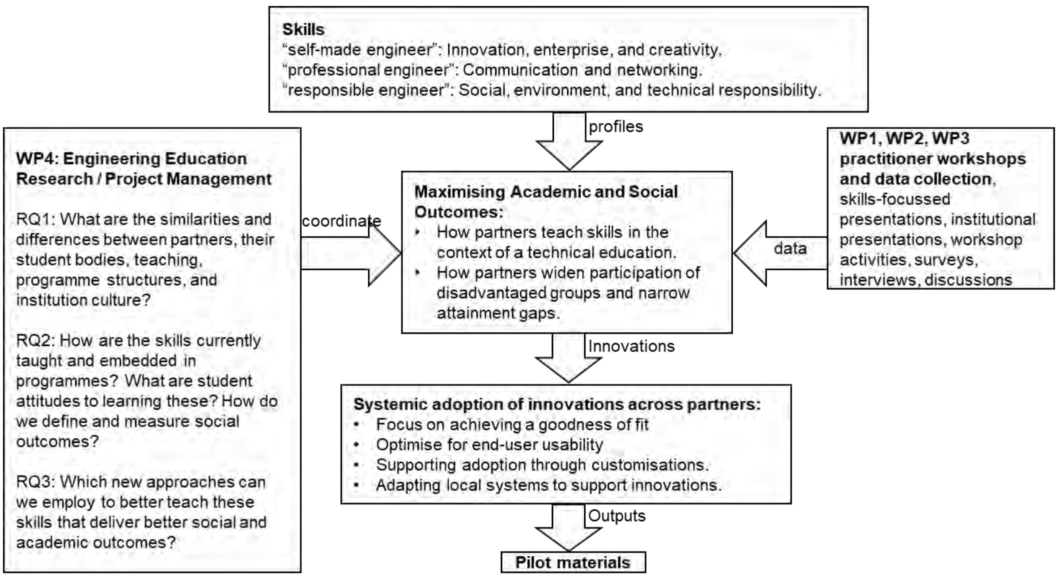

Fig. 1. Project workflow.

3.2 Mapping engineering identities to skill taxonomies

So that all partners share a common definition for discussing the skills sets, the project will draw on existing skill inventories and taxonomies and map them to the 3 engineering cultures defined by (Berge, Silfver, and Danielsson 2019) as shown in Table 1.

Table 1. Engineering identities mapped to MASOEE skill mappings

Engineering identity as defined by (Berge, Silfver, and Danielsson 2019)	**MASOEE skill mappings to frameworks**
Traditional technologist (status-quo)	Science and maths, design, analysis, engineering tools and methods.
Self-made engineer (neoliberal trends)	WP1 Entrepreneurship: Innovation, enterprise & creativity Entercomp (Bacigalupo et al. 2016)
Contemporary technologist (progressive trends)	WP2 Solving complex challenges: Communication & networking. WEF 21st Century Skills (Soffel 2016)
Responsible engineer (sustainability trends)	WP3: Sustainability competence: Technical, social & environment responsibility. EU GreenComp (Bianchi, Pisiotis, and Cabrera Giraldez 2022)

3.3 Mixed methods

(Johnson and Onwuegbuzie 2004a) argue that it is the diverse nature of mixed methods that results in higher quality research. The MASOEE project strategy is to examine the similarities and differences between institutions in terms of student bodies, teaching, programme structures, and institutional culture. Whilst it is possible to gather some of this data within a quantitative manner, exploring student attitudes needs a more qualitative approach, leading to the decision to adopt a mixed method research design. To help understand how this mixed method research has been structured, the research questions were broken down into each method used to help answer it and whether it is qualitative or quantitative (Table 2).

3.4 Survey

The survey was designed to obtain an overview of current professional skills teaching practices, similarities and differences between the different partner universities, and demographics (current year of study, foundation/pre-year, discipline, University, country of birth, country they attended secondary school in, measure of disadvantaged status). Each partner shared how disadvantage was monitored within their own country. Whilst there was some crossover between the partners in terms of how they monitor disadvantaged status, there are also some differences (Fig. 2).

3.5 Documentation, interviews, and focus groups

The qualitative aspect of the research encompasses documentation, interviews, and focus groups, which explore attitudes and approaches, and will build on information found within the survey phase. Interview and focus group schedules were developed to guide the process. In terms of document analysis, the team created a curriculum grid, entering information on modules that are running at each institute.

Table 2. Research methods identified to answer research questions

Documentation (Qualitative)	Student Survey (Quantitative/ Qualitative)	Interviews (Qualitative)	Focus Groups (Qualitative)	Case Studies (Qualitative)
University college/school websites (RQ1/2): Teaching, Programme structures, Institution culture, How skills are taught, acess to scholarships (identifying support for disadvantaged)	**Demographic (RQ2):** Disadvantaged (e.g. Sutton Trust, UK), Free school meals, first in family to go to university, postcode. **Similarities and differences (RQ1)**: Engineering partners, Student bodies, teaching, Programme structures	**Attitudes (RQ2):** Student attitudes to learning these skills Approaches (RQ3): Which new approaches to better teach these skills to deliver better social and academic outcomes.	**Approaches (RQ3):** Which new approaches can we employ to better teach these skills that deliver better social and academic outcomes.	**Similarities and Differences (RQ1):** How skills are taught **Similarities and Differences (RQ1):** How skills gaps are partners closed **Approaches (RQ3):** transfer best practice.

Measure of disadvantage	UK	SWEDEN	ITALY	FRANCE
Free School Meals (FSM) at secondary school	✓			
Home postcode	✓		✓	
Parents attended university	✓		✓	
First Language		✓	✓	
Government Scholarship			✓	✓
Paid employment whilst studying				✓

Fig. 2: Measurement of disadvantaged students in the four partner countries

3.6 Case study documentation: best practice adoption across partners

MASOEE partners exchange best practice through sharing case studies. Moreover, to facilitate integration of new practice into their institutions, the case studies are structured drawing on the literature of diffusion of innovations – notably the propagation paradigm (Froyd et al. 2017) where the key object is to maximise the efficacy and the fit to the partner to allow for meaningful adoption. The characteristics of this propagation paradigm include: The focus being fit rather than evidence of efficacy. This requires dialogue with partners for how to adapt an innovation at a partner; The innovations should be characterised by usability to provide generalisation to other settings, rather than strong data; Partner interactions through case study presentations ought to support adoption rather than raise awareness; The different instructional systems of the partners e.g., Canvas, Moodle, must be considered as part of the case study so that technical frictions can be reduced.

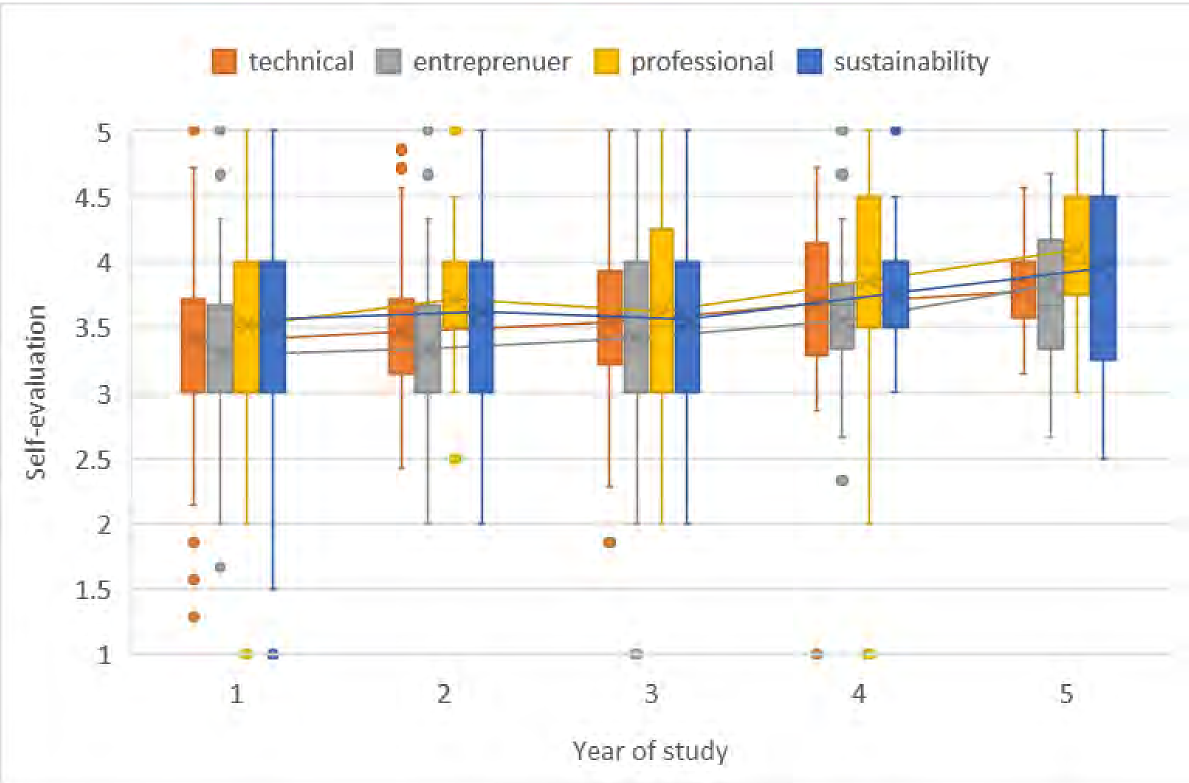

Fig. 2 Self-evaluation of MASOEE skill mappings against year of study (n=535)

4 PRELIMINARY RESULTS FROM SURVEY

As outlined in Table 2, a student survey is being conducted by all partners. The survey has been translated into the language of each partner's country and captures demographic information as well as attitudes to teaching skills and student self-rating of abilities in each of the skill sets outlined in Table 1. Early results highlight differences in students' self-evaluation of the MASOEE skills mapping they are learning; e.g. for one partner's cohort (Fig. 2) where we compared skills against year of study, we observe that there is a gradual upward trend in most skill levels with some difference in variances between year. Although further analysis is needed, there are a couple of stand-out results that are driving our focus group and interview discussions: Sustainability skills (blue) are fairly consistent from years 1-3 but increase in years 4-5. Entrepreneurship skills (grey) follow a similar trajectory although in the first 2 years there is a greater concentration of students rating themselves as lower, resulting in a smaller variance. Going forward, it will be interesting to compare institution’s cohorts and differences and relate these to their curriculum and culture.

5. SUMMARY

Accreditation standards and a globalised engineering educator profession can bring about harmonization of European engineering degrees. However, we enjoy different cultures and contexts, including student and staff diversity, language, national priorities, facilities, exchange opportunities, and industry collaborations. The MASOEE project is a creative learning process to share this knowledge and expertise.

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ENGINEERING STUDENT BELONGING TO PREVENT EARLY LEAVERS THROUGH CURRICULUM DECOLONIZATION, ACADEMIC SELF-CONCEPT, AND PSYCHOLOGICALLY SAFE TEAMWORK

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ABSTRACT

The proportion of early leavers from engineering degrees closely follows the higher education sector throughout Europe; around 10% leave before graduation. Students are more likely to drop-out if they do not feel that they belong in the learning community. While research shows that academic achievement is a primary factor contributing to student drop-out, other student-centric social factors, such as belonging are equally important to student drop-out rates within higher education. The aim of this paper is to present a model constructed on student belonging. The model consists of 3 pillars, namely academic self-concept & professional identity, psychologically safe teamwork, and decolonisation. The study was based on the development and continuous refinement of interventions that could assist students with feeling a sense of belonging. While the primary intention of this project is to present a body of work that highlights belonging as a contributing factor that may be pivotal to a student remaining in higher education or dropping out, readers will also learn about how best to support students in gaining a sense of belonging through self-concept, providing safe teamwork and by decolonising the curriculum.

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1 INTRODUCTION

A loss of human capital and talent for the engineering sector is a potential outcome of high student attrition in engineering degrees - the number of students who leave their programmes before completion. This exodus compounds the STEM skills shortage reported across many industry sectors. Around 8% of UK students leave university during their first year of study which is replicated elsewhere in Europe where 11.4% of men and 7.9% women in 2021 are early leavers (European Commission 2022). However, often, the situation in engineering faculties is reported higher than their university-wide averages (Andrews, Clark, and Phull 2020).

There are many factors identified in the literature since the 1970s as to why students leave early, and indeed many strategies suggested as to what universities might do to keep them. In (van den Bogaard 2012)'s review of this literature and its applicability to the engineering education context in the Netherlands, several frameworks are analysed identifying these factors. Broadly speaking, most factors are student-centric including background such as age, disposition e.g. motivation, and behaviour e.g. time commitment. Contrastingly, the education setting contributes to attrition through several factors including structures, pedagogies, and how students and staff interact. Although this review finds that the single most consistent and stable predictor of retention is students' ability, it makes the important observation that student abilities are influenced by the education experience we deliver.

So how do we change our educational settings to improve students' abilities and thus reduce the dropout rate? In this work we propose a model to improve students' sense of belonging. This choice is not casual, as belonging has long been established as a success factor which indeed might be inhibited by an over-representation of introverted students in engineering (Wilson, Spring, and Hansen 2008). Our work focuses on three pillars: academic self-concept, psychologically-safe teamwork, and decolonisation. We developed this work by integrating several ongoing studies across the University of Birmingham in the United Kingdom (UK). This is a research-focussed university with approximately 5000 engineering students across 6 faculties and a student cohort roughly split equally between international and home students. We recognise that different students and faculties may have different needs and challenges. Indeed, there will be other factors beyond our control that affect student success such as their personal circumstance, health, and finances. However, we believe that by focussing on these three pillars, we can enhance the education for all students.

2 THE MODEL

The primary factor for students leaving university may often be related to students' academic achievement (Greenland and Moore 2022). Decades of research have been dedicated to innovative pedagogies to improve student success. However, a more holistic approach may be necessary as good academic results may not be the only factor contributing to the drop-out rates.

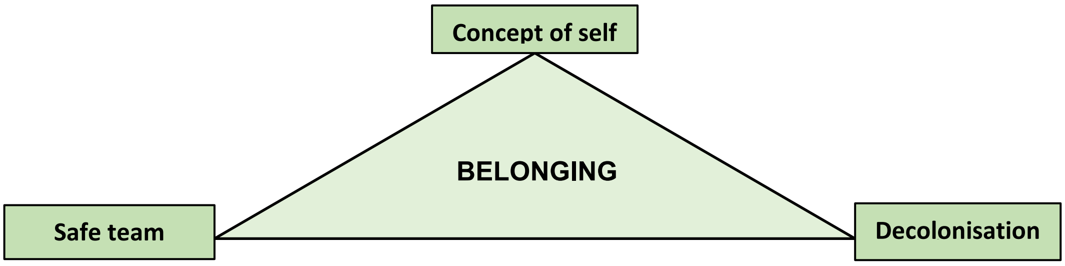

Fig. 1. Belonging model.

For this study we have identified belonging as one of the key factors to students' wellbeing, contributing to whether student successfully completes their degree. We propose a model (see Fig. 1) that underpins student belonging to reduce or prevent early leavers. The model consists of 3 pillars, namely decolonization of the curriculum and of teaching and learning practices, academic self-concept, and psychologically safe teamwork which together provide a foundation on which a sense of belonging can be built. This study was designed and implemented to address the different pillars of the model.

We address academic self-concept & professional identity – a person's belief about their abilities, role, and purpose – since it is likely to be lower for under-represented student groups because of the reciprocal relationship with, and interpretations of, their environment. We discuss our development of teaching interventions to better develop metacognition and self-regulation to raise self-concept. Psychologically safe teamwork – where all members are comfortable and perform optimally - is an area that many students struggle with. Several suggestions explain the difficulties in group dynamics such as language differences, cultural incompatibility, social skills, and individualistic competition. We outline how cultural differences are being supported through early interactions within a group setting to offset many of these issues. Decolonisation – teaching engineering in a way that is fair and effective across ethnic, racial, social and cultural perspectives - is widely considered essential (Bhambra, Gebrial, and Nişancıoğlu 2018) yet challenging for STEM, with a disproportionate effect on minority students which itself risks damaging the cohesion of entire cohorts. It is crucial to shift the conversation, through appropriate research, from "why decolonise?" to "why not?", and we describe how this research can be developed into educator trainings to help demystify the term.

3 SELF-CONCEPT

The first aspect of our model is to understand how students see themselves. We are undertaking 3 projects in this area focussing on academic self-concept, professional identity, and metacognition respectively.

3.1 Academic self-concept for foundation year students

Academic self-concept (ASC) refers to a student's own evaluation of their academic abilities. It is frequently indirectly referred to with other names such as self-reported grades. In a recent study based on a longitudinal dataset of children in the UK born 1989/1990, the authors found that students with higher ASC were more likely to progress from compulsory, through to non-compulsory then higher education, and that these findings were applicable in all subjects including engineering (Marsh and O'Mara 2008). Although the study did not look directly at the relationship between ASC and retention once students reached higher education, based on ASCs correlation with positive trajectories in education, it is reasonable to assume that this continues during higher education.

To investigate ASC in our context, students enrolled on the foundation year programme were invited to complete a survey of ASC in their first month on the programme. The survey tool used was the Academic Self Concept Scale (ASCS) (Reynolds 1988), a 40-item Likert-scale survey with questions such as "Being a student is a very rewarding experience", "No matter how hard I try I do not do well in school" and "Others view me as intelligent". Items are scored between 1 and 4, so the metric mean is 2.5. 149 students were invited to complete an online ASCS survey. 33 responded demonstrating a range in ASC between 2.05 and 3.50 with a cohort mean of 2.71 for respondents.

To improve ASC scores, we have introduced a 'Guided Study' in the academic year 2021-22 with the aim of developing student belonging by providing opportunities for peer supported learning and structured yet informal contact sessions with at least two academic staff. The goal is to create the opportunities described above to facilitate informal interaction between students and academics, and to support students in developing peer relationships and their own ASC building on the principal that transition to university activities ought to be student-centred and provide informal opportunities for relationship building (Briggs, Clark, and Hall 2012).

Informal feedback from students indicated improved scores, and in future we hope to demonstrate more improvement as a result of engagement with interventions building on Guided Study.

3.2 Professional identity framework for student years 1-5

Complementing the ASC for the foundation year students is concept of Professional identity which we consider for all subsequent years of study. The Cambridge dictionary defines identity as "who a person is, or the qualities of a person or group that make them different from others". In engineering education, students' engineering identity affects their performance and career choices. Engineering schools can use this concept to understand their students, widen participation, and improve career outcomes (Hansen, Henderson, and Shure 2023).

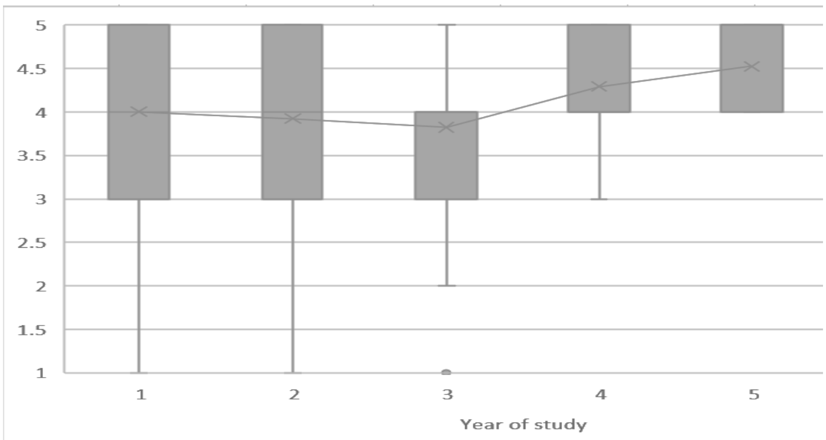

Fig. 2. Distribution of students (n=506) self-concept of identifying as an engineer

We developed a professional identity framework to help engineering faculty to improve their programme development, module designs, and motivate students' skill development and inform their career choices (Cooke and Hawwash 2020). The framework has a survey instrument embedded into the yearly academic review process that measures ASC by getting students to evaluate themselves against the full skill inventory. As a broad measure of identity, one survey question asks how much they agree with the statement "I identify as an engineer" on a 5-pt likert scale. We analysed this response for 536 students in electrical, civil, and mechanical disciplines against their year of study in 2022/23. We found a slight decrease in the average score between from year 1 (4.0) to year 3 (3.8), but then an increase for year 4 (4.3) and year 5 (4.5) (Fig. 2). This trend might be explained by the fact that a proportion of students leave at the end of year 3 with Batchelors degrees, while those who continue in years 4 and 5 are studying for at Masters level, which leads to them developing a stronger identity as engineers. We are further analysing whether this trend can help identify students who might be prematurely leaving with Batchelors degrees with lower than average ASC, despite having the capabilities to complete engineering study as Masters level.

3.3 Metacognition to improve self-concept

ASC requires students to reflect on their experiences and be effective learners. These skills are more formally referred metacognition and self-regulation. Developing metacognition and self-regulation are optimal skills that students should acquire to mature academically because students who can reflect on their thinking perform better academically. Being able to critically think about one's own learning process is vital for students to develop their own ASC and professional identity, especially in an environment where they may not have the experience or support that more established students might have. Acquiring such skills means that students can analyse their learning; determine whether their understanding of it is true; and develop a feedback mechanism with which to constantly evaluate the quality of their learning. This may lead to a more positive academic experience overall.

Furthermore, metacognition is a crucial part of developing an academic concept of self. Over the past 3 years (2020/21 to 2022/23) a project is underway within the School of Computer Science (SoCS) to evaluate the effects of applying metacognitive skills in an undergraduate and post-graduate curriculum. From 2020/21 academic year programming modules taught to both cohorts, included several tools to assist them with acquiring metacognitive skills and therefore being able to reflect on their learning. This was particularly important during Covid when students' learning was fully online. Although a blended learning approach has been adopted post-Covid, the use of these tools has been maintained. For example, the use of Kahoot is an effective tool for both educators and students to reflect on their teaching and learning (Altawalbeh and Irwanto 2023). Within a classroom environment, regardless of class size, educators can instantly be provided with feedback on how students are performing. Conversely, students can measure their own learning.

Currently, students complete a weekly reflective online survey that prompts them to think about their understanding of the content; lab work and tutorials completed; other formative assessments; and their level of engagement with the content. The survey provides students with a score, then if their score is below a particular number, further suggestions on how to improve their learning are offered. Current data collection for 2020/21 to 2022/23 shows that although students initially engage with metacognition thinking tools, they very quickly then disengage. For example, engagement dropped steadily from 349 students in the first week of class to a mere 7 in the last week of class and averaged only 75 students per week.

However, research shows that when a tool is fun students tend to continue using it (Licorish and Lötter 2022). For example, Kahoot quizzes were also presented to students weekly (throughout the same academic periods), and while engagement fluctuated more, it remained high every week with an average of 244 students applying the tool. One further difference between the implementation of the two tools mentioned above is that the Kahoot quizzes were run during class time, while the Canvas quizzes were available to the students at any point during the week.

From these results the following points of interest become apparent: metacognition, while intrinsically a solitary activity, is enhanced by the support of academics and peers; secondly making the process of metacognition more fun results in higher engagement. By making the tools for metacognition, and the skills to use them, more easily available to all students, those students who might not have a well-defined academic concept of self, have an opportunity to improve this concept of self.

4 PSYCHOLOGICALLY SAFE TEAMWORK

Whereas the self-concept pillar of our belonging model helps students to develop individually, the safe teamwork pillar focuses on their relationships; we want all students to feel secure and confident when collaborating. In many engineering programmes including ours, home students perform better than international students. This is not just because of language skills, as our data from our postgraduate Master’s courses shows; the attainment gap exists even when international students studied in English for their first degree. We aim to identify and close this gap.

For pedagogical benefits, increasing amounts of study time are spent in groupwork. International students frequently achieve a higher grade in group assignments when compared to their individual work demonstrating the power of diversity (Channon et al. 2017). However, they also face challenges, particularly when groups are mixed between home and international students (Baker and Clark 2010). These challenges include communication, lack of group work experience, different expectations and cultural norms. This pillar aims to improve students' performance by modifying group structures, assignments, and staff and student training on group work skills. The first stage of this is to observe groups working together and identify if any of the issues highlighted in academic literature are present. A group of 58 students (32 international) were observed working on a series of challenges relating to systems engineering and ergonomics during an intensive module week. Groups or 6 or 7 were allocated randomly and students were expected to organise team roles themselves.

We observed that in all groups a home student became the leader and allocated duties. The exercise briefs allowed for solutions geared to international audience, yet groups usually focussed on the home student preference; home students often gave opinions first and led the group in their preferred direction. Home students took on a parent/teacher role, with international students asking questions. After the first day a number of international students did not return to the group sessions. These observations have led to our questioning the structure and content of all groupwork that is completed by students; group dynamics will be affected by the exercises students are asked to complete e.g. if an exercise can be completed by one or two students then home students have less incentive to involve international students, particularly if there are perceived communication barriers. Moreover, a project based in UK industry puts international students at an immediate disadvantage and are less likely to lead.

The next step in this work is to change these group dynamics and make group work psychologically safer. We are encouraging staff to consider cultural differences to make group exercises more inclusive, better contextualising tasks to several countries. This way, international student's knowledge becomes valuable to the group. Furthermore, we are improving teaching of interpersonal skills and how other cultures communicate.

5 DECOLONISATION

This pillar focuses on decolonisation's contribution to students' self-concept, attainment gaps, and their interaction. Evidence shows persistent gaps in attainment for underrepresented groups. Widening participation processes have been broadly speaking successful in the UK Higher education systems, but gaps persist at the award level especially between BAME and white students.

To address persistent gaps in attainment for underrepresented groups, decolonising the curriculum is necessary. This involves recognising and addressing the legacy of disadvantage, injustice, and racism. Curriculum decolonisation covers all aspects of learning, but focusing on student perceptions and relationships is especially fitting in our model. We commissioned a study in 2020 to explore academic disparity, also known as the "ethnicity attainment gap" (Rana et al. 2022). The study aims to investigate student perspectives and perceptions on this topic and offer strategies to tackle them. The results indicate that it is crucial to cultivate a stronger sense of belonging among students, both with their peers and with staff members. We found that fostering a sense of belonging is an important first step towards achieving the necessary cultural and behavioural changes to close this gap. Other researchers also consistently find a sense of belonging is linked to success e.g. (Pedler, Willis, and Nieuwoudt 2022).

While acknowledging that the causes behind the academic disparity are highly complex (Stevenson 2012), our study's key finding highlighted that only 37% of BAME students surveyed felt a sense of belonging, compared to 83% of white students. Despite accounting for multiple socio-economic factors and previous academic achievement, questions remain that can be effectively addressed by exploring students' beliefs about their potential. Stevenson's research revealed that many minority ethnic students have internalized negative stereotypes associated with their ethnic group, which may lead to self-doubt, underachievement, and a mismatch between their perceived and possible future selves. One notable difference between the attitudes of BAME and white students in both studies was their intentionality in contacting academics for support. Interestingly, this is not due to fear of discrimination, but the students' perception of their own self-worth and the likelihood of establishing meaningful dialogue with staff members. This is clearly represented by the fact that a minority of BAME students find their lecturers approachable, compared to the majority of white students surveyed.

Despite the complexity of the problem and potential solutions, it is crucial to openly address race and ethnicity, particularly in STEM subjects, where the debate is lagging behind. Decolonizing education involves bringing these issues to the forefront of student experience design and evaluation, ultimately promoting a greater sense of belonging and improving educational and social outcomes. In this context, there are three areas of focus for intervention: promoting a sense of belonging, improving staff/student relationships, and increasing staff diversity, especially in leadership roles. We plan to investigate student belonging within their academic community, considering the impact of Covid since our 2020 study. Additionally, we will examine staff perceptions and attitudes.

6 SUMMARY

“Engineering student belonging” aims to improve student success through integrating and developing measures and interventions that focus on self concept, safe teamwork, and curriculum decolonisation. In this paper we have raised awareness of several of its foundation projects to inform training of educators and the development of teaching interventions.

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Exploring the potential for scripting with simulation in engineering education – practical examples using Python and Ansys

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ABSTRACT

The ability to use scripting tools to harness the power of complex engineering software is not only critical for research and industry, but also offers opportunities for student learning and development. This paper covers two ways in which undergraduate engineering students have been exposed to Ansys simulation tools to be controlled from Python programs. A pilot series of 'CodeFests' have been held in partnership with university engineering departments, offering a fun way for students to engage with Python coding while exploring the power of scripting to optimise or iterate on solutions. These have used the PyMAPDL structural simulation library, leveraging students' existing understanding of mechanical engineering problems to provide a 'way in'. Students tackled simple mechanical challenges, but with a twist – such as an optimisation requirement which would be beyond manual ability to solve in the time available. In parallel, the potential for scripting tools to provide 'lab in a box' type experiences harnessing the most powerful simulation tools has been investigated. A basic prototype to replicate a fluids lab exercise involving a cylinder in a wind tunnel was created inside a Jupyter Lab running Ansys Fluent through the PyFluent library. This provided a simple, customizable way for students to interact with a 'lab' powered by simulation, without needing to teach them the Ansys Fluent interface and controls first. Both these projects show the potential for harnessing simulation power further in engineering education through scripting methods, to engage and empower the engineers of tomorrow.

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1 INTRODUCTION

1.1 Scripting Tools and Simulation

Many engineering software tools are designed with specific purposes or specific user groups in mind, which can limit their functionality for other user groups or for people who wish to use them in combination with other tools. The ability to use scripting tools with software, however, opens up a much wider variety of possible use cases, and creates opportunities for both research and teaching.

Since 2020 [1], Ansys has been releasing 'PyAnsys' libraries, which are an Open Source set of technologies that allow users to interface with Ansys solvers such as MAPDL (Mechanical), Fluent (Fluids) or AEDT (Electronics) from an external Python environment. This then allows users to connect these solvers and their outputs to the richness of tools in the wider Python ecosystem.

The value of this in a research or commercial engineering environment is clear, and PyAnsys is already being used in research groups to couple Ansys simulation software with optimisation routines, machine learning algorithms and more [2], [3], [4]. However, an opportunity also arises to deploy these tools within the undergraduate engineering curriculum, where other benefits could be found.

1.2 Motivation

As a leading simulation software company supplying software across a wide range of industry sectors, we at Ansys are aware of the needs of students as they enter the work force when it comes to software tool understanding, etc. But there is evidence that there is a large gap between what industry expects from new graduates and the curriculum students are being taught [5], [6], [7]. One skill in particular that has been highlighted as necessary for the next generation to have is experience with industry-level software [5]. Based on understanding of the value coding and simulation have in industry, and the possibilities which arise from combining the two we have been piloting potential academic-industry engagement in this area in two ways: organising 'CodeFests' and investigating lab work using Jupyter Notebooks and simulation.

1.3 Practice Undertaken

This paper explores two different ways of exposing students to scripting tools: firstly, as a tool for them to explore themselves, enhancing their skillset, and secondly, as an enabling tool to allow introductory students to benefit from advanced software they might not otherwise use.

A pilot series of 'CodeFest' events have been held at a small number of universities, giving students team challenges to tackle by writing their own code leveraging Ansys simulation software. The purpose of these events was to expose students to core scripting concepts and let them explore the possibilities when pairing programming with engineering simulation tools.

Separately, a pilot 'lab in a box' has been created which uses PyFluent within a Jupyter Lab environment to replicate a basic, introductory fluid dynamics lab. The purpose of this tool is to enable early-years students to benefit from industry-standard simulation tools such as Ansys Fluent underpinning an 'experiment.'

When looked at in one way, these two projects have opposite goals: the first, to expose students to more complexity and the ability to expand their engineering practice through coding; the second, to reduce the complexity of a simulation tool to help early-years students use it. However they both provide insight into the power of combining scripting and simulation in different areas of undergraduate education.

2 METHODOLOGY

2.1 CodeFest Events

There is a reasonably established tradition of 'hackathon' type events being used for student teaching, team-building and awareness-raising, as well as the more commercially-focused industry hackathons that have become common [8]. As a new set of software packages, PyAnsys is an ideal tool to introduce in the focused environment of such an event. However, since there was no free choice of which software students could use, these pilot events were advertised as 'Codefests' rather than true hackathons. A 2-day event was held at Cornell University in September 2022, followed by a 1-day event at Virginia Tech university in April 2023, with two further events planned in summer 2023.

CodeFest events were planned in coordination with an academic 'champion' at the university: a professor in the engineering faculty who felt that these events would benefit their students. The planning process involved not just the event logistics, but engagement with the academic champions in the months before the event to decide which types of challenges had the most valuable learning outcomes, since research on coding events shows that understanding desired outcomes is key to students getting the most out of the events [9].

The CodeFests were advertised to students 2-4 weeks ahead of the event, through a variety of means tailored to the university ecosystem: emails from faculty admin, a slide at the end of lectures to relevant student groups, small flyers for cafeteria tables and similar. In both cases this strategy was successful and over 100 students registered for each of the events. Students who attended were asked to form teams (and encouraged to make those teams cross-disciplinary) to attempt the challenges. Prizes of reasonable value (approx. 100 U.S Dollars per person) were offered to the winning team, with smaller prizes for creative solutions and other outstanding work.

2.2 Jupyter Lab 'lab in a box'

Jupyter Notebooks have become increasingly popular in education, as they offer a collaborative working environment which can combine text, images, code, web resources and more [10]. In engineering education, they can help to present complex computations in a way that complements traditional equation-focused teaching [11]. We therefore decided to explore this environment as a way to expose students to simulation with appropriate text, images and links to improve their understanding.

The ‘lab in a box’ style Notebook was developed as a project during a hackathon event, by a small team of 4 people over 24 hours. The motivation for creating a ‘lab in a box’ came from the idea of using powerful simulation tools in place of lab experiments, especially where universities may not have the resources for physical lab equipment, or remote learners may not be able to access it. Simulation can provide a ‘real world’ experiment to compare with theory, and there can be significant learnings from the visualisation capabilities in subjects such as fluid dynamics [11]. However, introductory level students who might benefit most from such visualisations are unlikely to have been trained in industry-standard simulation software, since this is time-consuming and often treated as a ‘readiness for industry’ course option in later years.

The project, then, was to attempt a proof of concept using Ansys Fluent with the python libraries available to create an easy-to-use lab, with simple instructions and user interface, powered by Ansys Fluent underneath. This was implemented in Jupyter Lab, which provides additional flexibility to Jupyter Notebooks. In particular, the ability to ‘hide’ code cells alongside the standard markdown cells means that the code running Fluent could be hidden from students taking the lab, but editable by professors or lab assistants if they wanted to add extra aspects to it.

3 RESULTS

3.1 CodeFest Events

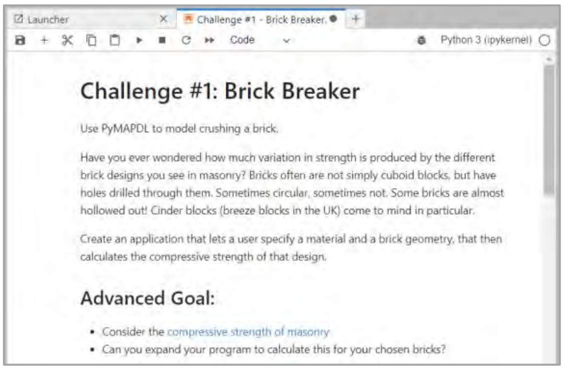
Overall, both events held to date have been judged to be a success, with positive feedback from both students attending and the professor champions.

At both events, despite targeting advertising primarily at undergraduate students, we found Masters and PhD students formed a large proportion of the attendees (34% at Cornell, 45% at Virginia Tech), showing that research students see the potential for combining scripting with simulation tools. Students attended from multiple disciplines: Mechanical Engineering, Computer Science/Computer Engineering and Aerospace Engineering dominated representation, but others from disciplines like Electrical Engineering also attended.

3.1.1 Cornell 2022 CodeFest Results

At this first event, student teams were presented with a choice between ‘guided’ challenges – essentially a set of coding exercises to work through with a small project at the end to apply their new knowledge, designed to introduce students to Python and programming – and ‘general’ challenges, which posed a problem, suggested an Ansys solver to use, and then left teams to create their own solutions using the PyAnsys libraries.

This was a 2-day event, and we saw significant drop-off in attendee numbers between the first day (a Friday) with 71 attendees and the second day (Saturday) with only 25 making it to the end of the second day. Those teams that did complete the challenges, however, produced excellent work showing they had mastered the necessary aspects of both Python and Ansys MAPDL to solve the problems we presented them with. An example of a challenge and a student team output is shown in Figures 1 and 2, showing how the students were able to engage with both UI creation through Python and controlling the MAPDL solver in the background.



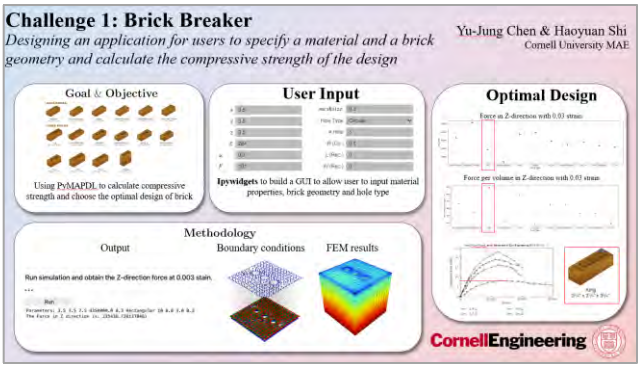
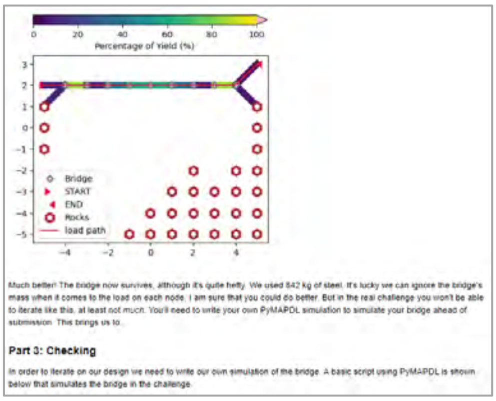


Fig. 1. 'General' challenge as presented to students

Fig. 2. Final results from one team tackling this challenge

3.1.2 Virginia Tech 2023 CodeFest Results

At the second event, we drew on learnings from the first and offered a new type of challenge which was partly guided and partly open-ended, where students were expected to use coding to find an optimal solution to a simplified 'truss bridge' type problem. This focused more on the coding challenge rather than the engineering challenge, since this was where students had struggled more at the Cornell event, but engineering understanding and validation of the team's solutions was still required for success. We also restricted the event to a single day, running from 9am to 6.30pm, and as a result saw very little drop-off in attendee numbers over the day.



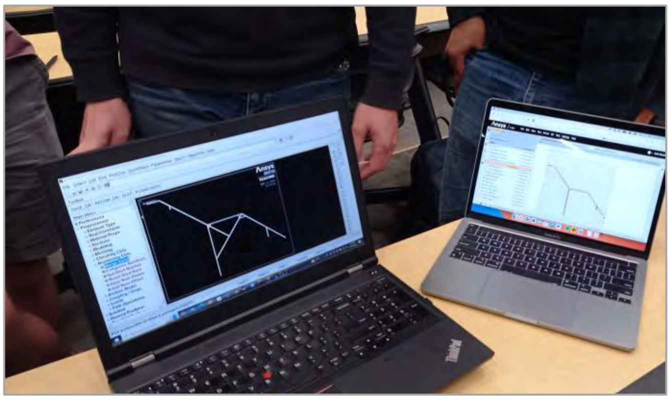


Fig. 3. Team guidance on the bridge challenge

Fig. 4. Bridge optimisation in progress on the computers of a student team

The challenge at this event was made easier to judge by the fact it was a simple optimisation problem – create a bridge across a matrix of nodes, minimise mass without yield failure. Students were encouraged to seek solutions through coding and then test these using PyMAPDL to confirm their behaviour and safety factor. We found that some students struggled to approach the optimisation problem through coding, preferring instead to sketch out potential design options on paper or whiteboards with engineering calculations done by hand. However, once students engaged with the challenge fully, they were able to harness the power of optimisation and validation. Introductory information for the challenge, and one team's bridge design in progress at the event, are shown in Figures 3 and 4.

3.1.3 Feedback, Lessons Learned and Future Plans

The students who participated in the events and were present at the end were asked for feedback, using an anonymous 'two sticky note' method: one for positive comments, one negative. At the 2-day Cornell event, there was sufficient drop-out on day 2 that this was not representative of most attendees. At the Virginia Tech event, however, this we gathered feedback from >50% of attendees, shown in Table 1.

Table 1: Anonymous feedback from VA Tech Ansys Codefest participants

'What I enjoyed'	'How could we improve?'
It was fun. Great staff.	Difficult documentation, wasn't helpful.
This was fun.	Instructions could be clearer, could be more code heavy.
Good food, not "corporate," friendly people, stickers, not too code heavy.	To me, it felt like the deadline is a bit short.
Food is good. Staff seemed sensible.	More detailed documentation would be preferable to get through details.
Impressed with the challenge. It helped me understand the application of Python in solving impossible challenges given the materials and constraints we had to work with this.	I'm not good at social coding. Love code and CAD otherwise. Not a Mechanical Engineer.
Python interface for APDL helps with automation. A good exercise to develop coding skills. Of course, I enjoyed the snacks and goodies.	More robust tutorial on problem. More focus on mechanical analysis portion such as learning about defining geometry and extracting results.
I made new friends. The problem was very interesting.	Finding documentation was a bit tough, process could be easier.
Good food, good swag, friendly staff, staff was nice and helpful.	Problem was too difficult to solve in the time given.
Food is great and great support from the staff.	Would prefer to see each group's designs at the end.
Met people, learned about how MAPDL is integrated into the backend of Ansys.	Problem is challenging for Python beginners. Need a leader of the team to do efficient work, but difficult in rapidly formed team.
Met fun teammates, creative problem solving, got more familiar with Python, had fun, and great networking.	Getting the coordinate was a big challenge, documentation was very difficult, took too much time to figure things out, didn't like the struggle signing in.
Learned a lot, met new people, great food, and great instructors.	Spend first hour explaining problem/example, Difficult for non-programmers.
Liked the format of challenges, the help, food, and the organization of event.	Tutorial on coding – many of us have never done coding.
Super helpful and friendly staff, loved the interactions.	Poor environment, simulations slow, some objectives/processes unclear.
Group work on the challenges, cool/helpful Ansys employees.	Syntax not clear, way too hard to submit answer, rubric unclear.
Team was helpful, challenge was fun to solve and fun to work with my team.	Documentation difficult to parse, incorrect values given initially, thought there would be more Ansys Mechanical, confusion on how to get there.
Format of challenges, comfortable environment, Ansys staff was helpful.	Teach more about Ansys before we start.
Good challenge, really enjoyed.	Demonstrate cases on familiar problems to make sure the programming in environment is understood before we start.
Challenge was fun and an interesting problem learning how to use APDL was more interesting than just Mechanical.	Start of program was too steep of a learning curve, felt more Python than Ansys. We were essentially blind trusting the program. If it ran, great. Need heavy programming skills to be able to push.
Engaging and fun, thanks for making me spend a laze Saturday a better way, helped me get new connections.	Wish there was more instruction on scripting, unclear instructions on actual challenge, wish there was more Ansys Mechanical integration
Whole experience was lovely. Loved to interact with new people and work together as a unit.	Wish there were more Ansys and less Python, based on fliers expecting more of a seminar, documentation needs improved.

Enjoyed how open ended the design process was. Left with a bunch of different ways to approach a problem.	Setup of challenge was frustrating, beams had to be 1 unit which is annoying, could do something more "polybridge."
Very well done overall, learned a lot about environment and scripting within it. Staff and experience was great.	
Intention is good, helpful to understand PyAnsys APIs, networking, fascinating problem and getting used to cooperation.	

Overall, the feedback shows that the social and challenge-related benefits of hackathon-types events were mostly successfully delivered, but there were challenges around coding skills level, particularly for students in engineering disciplines. Teams with computer scientists tended to do better for this reason, although teams of computer science students on their own also struggled, with engineering terminology or fundamental physical understanding. Teams combining both did best. Relatedly, another area requiring improvement, based on the feedback, is the documentation of the PyAnsys libraries, which were originally developed to support expert users of Ansys solvers (those who might already have been scripting in MAPDL, for example). For student users this documentation may need to make fewer assumptions of prior knowledge.

Our academic Champions at the universities were not asked for formal feedback, but both were positive about the events overall and interested in holding more in future. Our VA Tech champion was also interested in the potential to turn our ‘bridge-building’ challenge into a more open-ended teaching tool.

Two further CodeFest events are planned in 2023, at which the technical challenges and support required will be explored further, with one of these events focusing more on postgraduate/research students to see how this affects outcomes and feedback.

3.2 Jupyter Lab ‘Lab in a Box’ Results

The lab use case was based on an early-years fluid dynamics experimental lab run each year in the University of Oxford Engineering department, intended for students who have had lectures on potential flow theory but have not yet been exposed to real fluid flow. It consists of measuring the air pressure at points around a cylinder and showing how the measurements diverge from the predictions of potential flow theory downstream of the cylinder. This allows students to examine the assumptions of potential flow theory through exposure to real, viscous and rotational flow.

Since Fluent simulations can output pressure, they can exactly replicate this lab (minus additional learnings about physical measurement techniques), and potentially add more value through flowfield visualisations, velocity or possibly other variables.

3.2.1 Implementation Details

The Jupyter Lab exercise was thus designed to lead students through a reminder of what potential flow theory predicts, a discussion of the ‘experimental’ setup, and a slider which would allow them to explore different flow speeds spanning laminar and turbulent Reynolds numbers, all without needing them to directly interact with the standard Ansys Fluent user interface which is designed for experienced CFD users. Outputs in Jupyter Lab are in the form of the 2D velocity and pressure fields. Figures

5 and 6 show an example of the Jupyter Lab interface (including UI features such as sliders and buttons implemented using ipywidgets[12]), and the output in Ansys Fluent if it is chosen to show Fluent on screen, or in the Jupyter Lab interface.

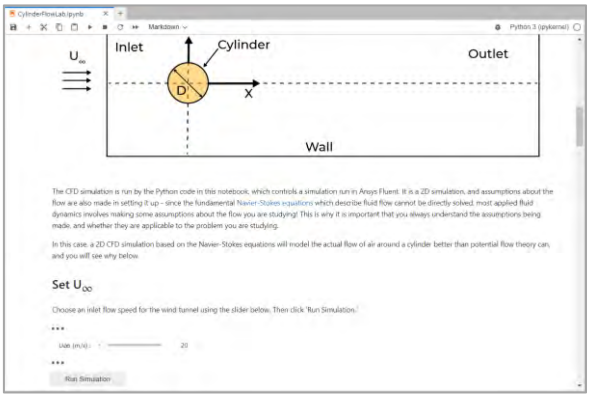


Fig. 5. Jupyter Lab interface with instructions and simple button/slider controls to set values in Fluent and run the simulation

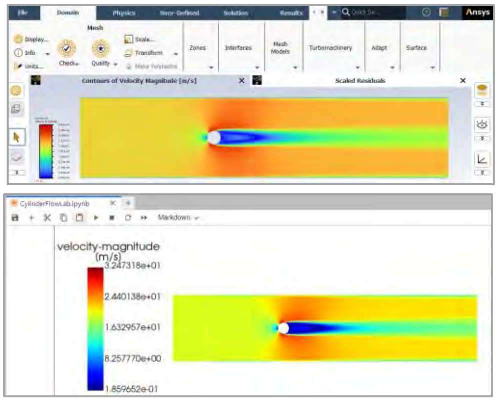


Fig. 6a) and b) Resultant velocity flowfield displayed in a) Ansys Fluent and b) Jupyter Lab, depending on GUI chosen

3.2.2 Lessons Learned and Future Plans

Overall, the proof of concept Jupyter Lab was relatively easy to create – this is something that we could envision professors or student assistants being able to make in future, and customise to their lab requirements.

We plan to share this Jupyter Lab resource in the second half of 2023 with academic users, and get feedback on the ease of use and ease of customisation. We also plan to develop similar resources for other simulation software, for example for mechanical or electronics labs, using PyMAPDL, PyAEDT or other PyAnsys toolkits.

4 SUMMARY AND ACKNOWLEDGEMENTS

In summary, we have found significant interest from students in learning how to couple scripting with simulation tools, for their own development and for their degree work, though there are some inherent challenges to overcome in introducing these through ‘hackathon’ type events, particularly around gauging students’ skills at coding ahead of the event and adapting material appropriately.

We also believe there is a significant opportunity in harnessing the power of scripting, and Python in particular, where simulation tools allow this, to deliver simulation outputs in a format which is accessible to untrained, early-years students. Based on our experience, there are potentially some easy wins in this area for simple use cases where visualisation would strongly support learning outcomes.

We would like to acknowledge the support of Professor Rajesh Bhaskaran at Cornell University and Professor Bob West at Virginia Tech University for partnering with us to deliver the CodeFest events on their campuses. We would also like to acknowledge Dr Christopher Vogel at the University of Oxford for confirming details of the fluid dynamics lab exercise which we attempted to replicate in Jupyter Lab.

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ENGINEERING FOR ONE PLANET: RESOURCES FOR INFUSING SUSTAINABILITY AND LEADERSHIP COMPETENCIES ACROSS ALL ENGINEERING DISCIPLINES

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Conference Key Areas: *Addressing the challenges of Climate Change and Sustainability, Embedding Sustainability and Ethics in the Curriculum*

Keywords: *Sustainability, EOP Framework, EOP Teaching Guides, EOP Network*

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ABSTRACT

Engineering for One Planet (EOP) is an initiative to transform engineering education and equip all future engineers across all disciplines with the fundamental skills and principles of social and environmental sustainability.

Catalyzed by The Lemelson Foundation and VentureWell in collaboration with hundreds of sustainability advocates across sectors, the EOP initiative envisions a world in which all engineers play a critical role in ensuring that the solutions of today do not become the problems of tomorrow, restoring and regenerating our environment, and improving lives for all.

EOP is accelerating curricular transformation by supporting faculty change efforts and fostering collaboration among stakeholders across sectors. Experts from academia, civil society and government co-developed the EOP Framework in 2020, including an adaptable and adoptable menu of core and advanced sustainability and leadership learning outcomes. Five universities pilot tested the EOP Framework in curricular changes over two years, and the EOP Framework was revised in 2022. In 2023, EOP launched companion teaching guides with step-by-step guidance and free teaching resources for integrating learning outcomes from the EOP Framework.

To date, more than 120 faculty have used the EOP Framework to generate curricular changes in dozens of diverse engineering disciplines and programs, impacting thousands of students. EOP makes its teaching tools available for free and is designed for flexible adoption and adaptation to encourage rapid expansion of sustainability into engineering education.

This presentation will enable participants to learn about the resources available through EOP, gain ideas from successful curricular change approaches and get involved in EOP’s growing global community.

1 INTRODUCTION

1.1 Rationale

Sustainability has been identified across all sectors, from government to industry to academia, as a top priority, especially as it relates to developing leading edge solutions to national and global challenges (e.g. climate change), protecting nature and the environment, ensuring environmental justice, and advancing human health, welfare and prosperity. Large industrial firms from across the globe are prioritizing sustainability and recognizing its importance to future national competitiveness and growth, leading to gaps between the demand for green skills and the supply of talent [1]. A recent study with nearly 7000 student respondents from around the world found that 90% of students were concerned about the effects of climate change, and felt that sustainable development should be universally taught in higher education yet only 26% of respondents felt their coursework was covering these issues in depth [2]. The environmental challenges we face are increasingly complex and severe, and disproportionately impact historically marginalized and low-income communities due to longstanding systemic injustice and discrimination. The demand for STEM graduates and green skills are both rapidly increasing, requiring an escalation of sustainability-infused STEM education.

Successfully addressing global challenges requires fundamental and systemic change in how we define the role of engineering and engineers, collectively prepare the 21st century workforce, and develop cutting-edge technological solutions that are not only more sustainable but net zero and even regenerative. It also requires fundamental and systemic change in who will want to become an engineer, graduate as a trained engineer, and pursue a career as a professional engineer. It is imperative that people from communities that bear the brunt of the negative impacts of climate change and environmental degradation are able and encouraged to share their perspectives, knowledge, and lived experiences as engineering leaders and problem-solvers [3],[4].

Engineering education operates within a complex system of interdependent stakeholders and policies, all of which exert forces on education but do not work in unison. Among these stakeholders are professional engineers, engineering employers, professional engineering societies, engineering education accreditation bodies, government regulators and consumers. Efforts to change engineering education, such as the Engineering for One Planet initiative, must acknowledge, account for, understand, and engage the interests of diverse stakeholders and foster collaboration.

1.2 Background

Beginning with research efforts in 2017, the Engineering for One Planet (EOP) initiative was officially launched in 2020. EOP is a coalition of hundreds of organizations and individuals seeking to transform engineering education to prepare all future engineers with the sustainability and related professional skills and knowledge that are increasingly required in engineering professions. Catalyzed by The Lemelson Foundation and VentureWell —two US-based non-profits created by the late Jerry Lemelson who was a prolific US inventor with over 600 US patents—the EOP initiative aims to engage stakeholders to infuse fundamental environmental and social sustainability topics across academic engineering curricula, programs, departments, and institutions.

With input from hundreds of experts in academic, industry and civil society, the EOP initiative has published the EOP Framework [5], a menu of student learning outcomes that all graduating engineers should acquire to ensure they are equipped to protect and improve our planet and our lives. Designed to be widely adaptable, the EOP Framework is mapped to ABET accreditation requirements [6], the United Nations Sustainable Development Goals (UN SDGs) [7], Bloom's Taxonomy [8], and simplifies the task of infusing sustainability and related professional skills into a broad range of engineering courses and programs. The EOP Framework serves as a platform for curricular change and has become a cornerstone of the EOP initiative.

2 METHODOLOGY

The EOP initiative has been developed and is evolving through collaboration among hundreds of sustainability advocates across sectors —from academia, industry, nonprofits, governmental agencies, accrediting bodies— geographies, and lived experiences. EOP seeks to ensure all future engineers across all disciplines learn the fundamental skills and principles of social and environmental sustainability. The results of a thematic assessment through in-person interviews and conversations with engineering practitioners and educators [9], [10] and the results of the EOP Literature Review Report [11] demonstrate the need for a sustainability implementation tool such as the EOP Framework as follows: engineers play a critical role in creating a healthy, flourishing world, and their work has outsized impacts on our world. Engineers must possess sustainable mindsets, skill sets, and professional preparation. This is necessary because the industry demands it and to ensure that the engineering solutions of today do not become the problems of tomorrow. However, many of today's graduating engineers are not learning sustainability-focused concepts, tools, and methodologies through their engineering educational training. Therefore, there is a need to intentionally incorporate these concepts into engineering education.

Numerous activities have taken place since the launch of the EOP initiative in 2020. Today, the EOP initiative utilizes three interrelated strategies to transform engineering education and ensure all engineers are equipped to design, build, and create in environmentally and socially sustainable ways: 1) EOP Teaching Resources: to facilitate curricular change, assessment, and peer learning (e.g., EOP Framework [5] and two companion teaching guides; Quickstart Activity Guide [12] and Comprehensive Guide to Teaching Core Learning Outcomes [13]) 2) Catalytic Grants: to foster curricular change through funding and mentorship (e.g., EOP Pilot Grant Program (PGP) and the American Society for Engineering Education (ASEE) EOP Mini-Grant Program (MGP), and 3) Collaborative Community: to support collective action across sectors to accelerate change (e.g., EOP Network).

2.1 Strategic Action 1: EOP Teaching Resources

The EOP Framework: Essential learning outcomes for engineering education (Fig. 1), first launched in 2020 and revised in 2022, is a cornerstone of the EOP initiative, the first of its kind to guide coursework, teaching tools, and student experiences that define what it means to be an engineer who is equipped to protect and improve our planet and our lives [5]. The EOP Framework is not a research framework but a practical implementation tool that supports educators in integrating environmental and social sustainability concepts and tools into engineering courses, programs, and departments. It provides faculty with a vetted menu of student learning outcomes that every graduating engineer, regardless of subdiscipline, needs to acquire to design, code, build, and implement solutions that are socially and environmentally sustainable.

Fig. 1. *Engineering for One Planet Framework Graphic [12]. Adapted from EOP Framework.*

The EOP Framework fills a gap in curricular development by detailing core environmental and social sustainability learning outcomes, as well as related leadership skills, that would enable all engineering graduates to be prepared to protect and improve our planet and our lives. It was co-created by a community of hundreds of experts from a range of identities, lived experiences, geographies, and sectors, including academia, industry, nonprofit, government, and philanthropy.

The EOP Framework comprises nine topic areas: Systems Thinking, Environmental Literacy, Responsible Business and Economy, Social Responsibility, Environmental Impact Assessment, Materials Selection, Design, Critical Thinking, Communication and Teamwork. Each topic area has a list of core and advanced student learning outcomes that are measurable and mapped to ABET's engineering accreditation requirements which are delineated through seven student outcomes in Criterion 3, which include sustainability competencies [6], as well as to the UN SDGs [7] and Bloom's Taxonomy [8].

Additionally, to better support faculty efforts to integrate the EOP Framework and sustainability-focused content into engineering courses and programs, two companion teaching guides were launched in 2023. The Quickstart Activity Guide outlines step-by-step and timed learning activities for one core learning outcome from each of the nine topic areas [12]. The Comprehensive Guide to Teaching Core Learning Outcomes provides learning activities to achieve each of the 46 core learning outcomes over the nine topic areas of the EOP Framework [13]. Both teaching guides and the EOP Framework are available for online and for free at www.engineeringforoneplanet.org.

2.2 Strategic Action 2: Catalytic Grants

Lemelson has funded three EOP grant programs, driving curricular changes and generating teaching tools, assessment tools and insights to help other faculty and institutions with similar efforts: 1) The EOP Pilot Grant Program (PGP) and 2) The American Society of Engineering Education (ASEE) EOP Mini-Grant Program (MGP), described below, and the 3) EOP Institutionalization Grant Program.

The PGP was designed to test the EOP Framework between 2020-2022. The program awarded seed grants to five US-based institutions (up to $40,000 each supported by community of practice meetings) to test the integration of learning outcomes from the EOP Framework in diverse curricular offerings.

Funded by Lemelson and launched in 2022, the MGP's first cohort awarded seed funding ($8,000 and mentorship) to 13 US-based schools, five of which are Minority Serving Institutions (MSIs) [14]. In 2023, the EOP MGP awarded 14 grants and is expected to award grants to approximately 12 additional schools in 2024.

Lemelson has also funded larger "institutionalization" grants to expand integration of sustainability at a number of higher education institutions and is engaging other funders to support EOP-related curricular changes.

2.3 Strategic Action 3: Collaborative Community

Due to the complex nature of the engineering education system, stakeholders identified the need for sustained collaboration to drive top-down and bottom-up approaches to transforming engineering education. The creation of the EOP Network in 2021 was a response to this need. This impact network seeks to foster collaborative actions among its membership of students, faculty members, higher education leaders, as well as industry, nonprofit, and government professionals. The network is voluntary, non-hierarchical, and self-governed, and it is supported by a paid network manager who facilitates member collaboration and project teams, plans and delivers events, and ensures the network operates effectively.

Other examples of collaboration through the EOP initiative include: the 2022 EOP Scaling for Impact Workshop supported by the National Science Foundation (NSF), and the development of an open-sourced Sustainability Toolkit to support United Kingdom-based educators in integrating sustainability into engineering education. A steering group including EOP representation and led by the UK's Engineering Professors Council (EPC) is co-creating the Sustainability Toolkit, which is funded by Siemens and the Royal Academy of Engineering.

3 Results

3.1 EOP Teaching Resources

Since its launch in 2020, the EOP Framework has been shared with thousands of academic and industry professionals in the US and around the world through presentations, reports, articles, and grantee activities. Examples of conferences in which EOP was shared include the ABET Annual Symposium, ASEE Engineering Deans Institute, ASEE Annual Conference, Annual Colloquium on International

Engineering Education (ACIEE), International Symposium on Sustainable Systems and Technology, and several other academic conferences.

Through the PGP, five diverse US universities pilot tested the EOP Framework in curricular changes that reached nearly 6000 students. In 2022, the EOP Framework was revised to incorporate feedback from pilot grantees and other stakeholders during an open commenting period. Over 600 comments were resolved that led to key modifications to the EOP Framework, including: defining and emphasizing sustainability as both social and environmental, revising outcomes to be measurable and tracked to Bloom's Taxonomy, aligning the EOP Framework learning outcomes to specific ABET student outcomes, and making a stronger connection to Diversity, Equity, Inclusion and Justice (DEIJ). The feedback also led to the development of two new EOP Framework companion teaching guides.

The EOP Framework has also been used to advance sustainability efforts internationally. Two examples include: use as a framing device where EOP learning outcomes were mapped to all courses in a new sustainable systems in engineering transdisciplinary degree program at the University of Calgary, and as a key resource to guide the development of the aforementioned Sustainability Toolkit for engineering education in the UK.

3.2 Catalytic Grants

As previously noted, the two-year PGP enabled five universities to pilot test the EOP Framework in curricular changes. PGP awardees found significant value in the EOP Framework and shared several key findings that can assist others seeking to make similar changes. In total, grantees integrated learning outcomes from the EOP Framework to develop or modify a total of 61 courses. Of these, 50 were required engineering courses, far exceeding the minimum goal of one course per institution, and impacting nearly 6,000 students in only 2 years [15].

The first cohort of the MGP concluded in January 2023 with an online, public symposium featuring poster presentations by all participating schools about their efforts and impact during the program. In total, awardees used sustainability-focused learning outcomes from the EOP Framework to develop or modify over 30 courses, reach over 1600 students, and train more than 30 faculty in less than a year.

3.3 Collaborative Community

In 2022, there was an open application period to join the EOP Network with a focus on intentionally broadening the participation of applicants from groups traditionally marginalized in engineering, including women and people of colour. A review committee selected 32 new members to join the EOP Network, expanding the network from 40 to 72 members. There is significant national and international demand to join the EOP Network. EOP Network members convened in person for the first time in October 2022 on the Boeing campus in Seattle, Washington. Participants formed team projects to pursue a variety of projects, including: developing a conference toolkit to support EOP outreach efforts, a guide to prepare students for sustainability-focused industry interviews, establishing an industry internship, conducting a funder landscape analysis, and establishing an EOP evaluation plan with key performance indicators.

The NSF-funded EOP Scaling for Impact Workshop engaged 100 stakeholders from various sectors and backgrounds to collaboratively identify approaches for taking the EOP initiative to scale. A report will be publicly disseminated in 2023.

4 Summary and Acknowledgments

4.1 Summary

Environmental and social sustainability have been identified across all sectors, from government to industry to academia, as critical for the health of our planet and lives. Through the vast reach and scope of engineering activities, engineers have the potential to positively address social and environmental challenges and/or to inadvertently contribute to future problems. To protect and improve our planet and our lives, all engineers must be prepared with fundamental skills in sustainability. Currently, most engineering graduates have limited exposure to sustainability in higher education. Transforming the engineering education system is complex and requires the collaboration of people and organizations across sectors including academia, industry, accreditation bodies, as well as the communities disproportionately impacted. The EOP initiative's vision is that sustainability will be a core tenet of the profession. To achieve this vision, sustainability must be infused throughout engineering education. Since its official launch in 2020 with support from The Lemelson Foundation, the EOP initiative has evolved and made significant strides to enable stakeholders to co-create the initiative's core tools and strategic roadmap and to spur curricular changes that have reached thousands of students. Together, the growing, international EOP community is helping drive curricular changes to infuse sustainability into engineering education and the engineering profession to ensure that all engineers are prepared to address today's challenges while seeking to maximize the positive and avoid the potential negative impacts in the future.

4.2 Acknowledgements

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STEM education and research at the University of Aruba for sustainable development of Small Island Developing States: Case studies on energy efficiency and waste management.

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ABSTRACT

SISSTEM "Sustainable Island Solutions through Science, Technology, Engineering and Mathematics" is a higher educational programme created in 2019 at the University of Aruba in response to the need for engineering education and research in Small Island Developing States (SIDS). In this contribution, the SISSTEM programme is introduced, and how SISSTEM equips engineering students with hard and soft skills while addressing local sustainability challenges is showcased through two case studies.

The first case study presents a bachelor course that combines sustainability theory with a teamwork project in which students conduct an energy audit to a local institution. With this course, students acquire skills to support the energy transition in Aruba. The second case study focuses on the involvement of university students in the creation of a citizen science mobile phone app to tackle waste challenges. This case study presents how students can become agents of change to contribute solving waste management challenges on the island.

Overall, these two case studies showcase how by combining theory and project-based education, students learn to integrate STEM knowledge into multidisciplinary solutions to complex sustainability challenges. In fact, given the cross-cutting nature of sustainability transitions, educating students in integrating the natural environment, technical, social, and economic aspects in engineering solutions is key to increase resilience of islands. As such, at SISSTEM, students acquire hard skills related to their engineering specialisation, as well as soft skills such as integration of disciplines, contextualization, and collaboration.

1 INTRODUCTION

1.1 Small Island Developing States

Small Island Developing States (SIDS) share sustainable development challenges given their remoteness, relatively small size, and fragile environments (Briguglio 1995). In addition, SIDS' vulnerability to external shocks is exacerbated by climate change (de Águeda Corneloup and Mol 2014), making sustainable development imperative to increase resilience in SIDS.

Technological innovation is key for sustainable development and in this regard, engineering education that integrates technology knowledge with principles of sustainable development is essential (Kamp 2006). While engineering education plays a fundamental role for sustainable development, STEM (Science, Technology, Engineering and Mathematics) education opportunities are not always available on SIDS. In this contribution, the higher education STEM programme named SISSTEM (Sustainable Island Solutions through STEM) at the University of Aruba is presented.

1.2 STEM programme at the University of Aruba.

Aruba is a Southern Caribbean island of 180 km² (Derix 2016) with a population of about 112,000 inhabitants (Central Bureau of Statistics Aruba 2020). Until 2019, engineering education was not available on the island, leading to talent drain and creating a dependency on external expertise (Mertens et al. 2023). In response to this need for engineering education and research, the programme SISSTEM was created at the University of Aruba through a collaboration with KU Leuven and with funding from the European Union (Mertens et al. 2022).

SISSTEM consists of a bachelor programme that offers three specialisations (Bio-environmental science; Information and Data Science; Technology and Engineering), a master programme, and 10 PhD research projects (University of Aruba 2023). The principles of education for sustainable development are applied, providing students with state of the art knowledge and equipping them with key skills to solve sustainability challenges (Mertens et al. 2023). In practise, educational material provided by KU Leuven professors is adapted to the SIDS context by academics at the University of Aruba (Mertens et al. 2022), fomenting the local application of STEM knowledge through field trips, practical assignments and educational projects. How local challenges are targeted through education and research is shown through two case studies elaborated in the sections below.

2 TARGETING LOCAL SUSTAINABILITY CHALLENGES THROUGH EDUCATION AND RESEARCH:

2.1 Case study A: Learning while promoting energy efficiency at local institutions.

The SISSTEM bachelor curriculum (University of Aruba 2023) includes the course "Integrative Project" in the 1st academic year with the purpose of teaching the integration of diverse disciplines on sustainability solutions. In this course, students conduct an energy audit of the building of a local institution, with the final goal of providing sustainability advice. Hosting parties have been the Dutch Marine base located in Aruba, the Queen Beatrix International Airport of Aruba and a local hotel named Amsterdam Manor. During the current academic year, the students are conducting the energy audit at the campus of the University of Aruba, and results are expected to be incorporated into the university's long-term sustainability plans.

"Integrative Project" is a six-month course that combines theory with practical assignments. During the theoretical module, students conduct a literature review on retrofitting techniques, a process during which they are motivated to think critically on the role of contextual factors when retrofitting buildings. Then, the students conduct field work in groups of 3 to 4 students. This consists of four site visits to the hosting institution which acts as a "client". During the first session, the students learn from the "client" the experienced operational challenges and how they expect the students' work to contribute to their sustainability plans. Based on the client's request, the students elaborate a measurement plan for collecting technical data during the second site visit. This includes observations and the use of instruments such as a thermal camera for detecting energy leaks, a lux-meter for identifying the potential use of natural light, and an air quality meter (Figure 1). Additional data required such as energy bills are requested by the students to the institution. During the third site visit, semi-structured interviews with employees from different departments are conducted. This interaction with the energy users is key for students to realise the role of social adoption when implementing technological developments. Based on the collected technical, social, and economic data, students provide to the "client" short- and long-term recommendations for energy efficiency. The results and recommendations are shared through an oral presentation and a written report delivered to the "client" on the fourth site visit (Figure 2).

Figure 1: Student collecting data with a thermal camera during field work.

Figure 2: Students presenting the results and sustainability recommendation to the "client".

Learning outcomes:

The learning outcomes are measured by assessing individual and group assignments. In addition, after course finalisation, students are asked to reflect on the learning experience (University of Aruba 2020).

With this course, students acquire skills to support the energy transition in Aruba. Learning to apply sustainability strategies at local companies has been defined by students as an eye opener – *“This course was something new, working with a client that has a set of requirements was something I have never done. Learning about data presentations, and how to write a proper assessment report was really eye opening.*”

In addition, the collaboration skills obtained by working with peers were also highlighted – *“During the integrative project I have learned to work better in the group and come to terms with compromises. I have also learned that in Aruba there are people/businesses interested in Sustainable Development”.*

Overall, this course has proven to equip students with skills necessary for sustainable development – *“I have acquired new skills, I have improved my management skills, acquired knowledge on policy making and learn about recommending”; “I have learned how to work better in a group and how to work in a professional way with organisations. I have also learned how to identify sustainability problems that are not obvious”.*

This case study presents how sustainability can be taught as a tangible concept by the inclusion of practical experiences in addition to theoretical lectures. As a lecturer, it is interesting to yearly evaluate and adapt the course content depending on the hosting institution. Other changes are made based on the skill needs by the cohort of students. For example, initially the course only included teamwork assignments, and later, it was decided to include individual assignments as well, for students to develop skills and knowledge both as individuals and as team members.

2.2 Case study B: Involving students in developing a citizen science mobile phone app to tackle waste challenges.

This case study presents the involvement of students in developing a locally applicable citizen science mobile phone app to track post-consumer waste. This was developed by applying a citizen science approach, which increases students’ engagement through active and research-based learning (Mitchell et al. 2017).

This project has been executed within the scope of the collaboration between the University of Aruba and KU Leuven which allows for international student exchange both ways. In this case, two software engineering students from KU Leuven showed interest in conducting together their master thesis on building the above-mentioned mobile phone application. While the app development task was assigned to the master students, a multidisciplinary team contributed to the design, including academics from KU Leuven and the University of Aruba. Input from independent software engineers and stakeholders in the field of waste management and citizen science was collected through brainstorming sessions. The app has been developed and tested at the campus of the University of Aruba, providing the opportunity to learn not only for the students developing the app but also for those students testing and evaluating the product.

The research conducted for the app development consisted of a desk research phase followed by an app development and testing phase. First, the students elaborated the research proposal. For that, the students conducted desk research to gain knowledge on the state of the art of citizen science mobile phone apps and on other fields key for developing this specific technology, such as plastic waste and SIDS' characteristics. In addition, brainstorming sessions involving students and academics, both from KU Leuven and from the University of Aruba, facilitated knowledge transfer across different educational levels and the integration of different points of view.

Next, the two KU Leuven master students conducted an international research stay of two months at the University of Aruba with the goal of developing and testing the app. First, the students focused on understanding the context, this included visiting a local plastic recycling centre which also acts as a collection centre for other waste fractions. In addition, the students sorted the waste disposed at the recyclable bins at the campus, identifying the most consumed products. Additional knowledge on the local applicability of the research was acquired through discussion sessions with expert software developers and an Aruban stakeholder in the field of plastic waste and citizen science.

The app was developed following an agile method. After four weeks, the first prototype was ready to be tested. The test was conducted by university students from different backgrounds during a workshop. A total of three workshops were organised, consisting of a brief introduction to waste followed by 20 minutes during which the students tested the app. Students were assigned random waste items representing the most common disposed products, and were asked to record data on the assigned waste items by using the app. The impressions on the usability and user-friendliness of the app were collected through a questionnaire completed by all workshop participants, a total of 46. While the user friendliness of the app was rated "very easy (to use)" by 69.6% of the participants and "easy" by the remaining 30.4%, the users recommended including additional descriptive features. For example, extra pictures and explanatory text to facilitate waste items classification, especially for the category "other non-recyclables". Of all the respondents, 82.6% agree that the app would help them sort the waste correctly. The motivational factors to use the app were ranked as follows: contributing collecting data (58.7%), reducing university's carbon footprint (45.7%), learning about recycling (39.1%) and getting rewarded for the contribution (15.2%). In addition, 78% of the participants showed interest in creating a log-in profile to follow personal waste recycling patterns. Another recommendation was to add in the app a language selection feature to choose from English, Dutch, Papiamento, and Spanish, the most widely spoken languages in Aruba. This was described as a key aspect for a successful local implementation.

After the testing phase, the thesis students worked on finalising the app (Figure 3). In this round, the students were able to incorporate their own ideas, as well as those provided by users from different backgrounds, providing an opportunity to make the creation process more multidisciplinary. The students concluded their assignment by disseminating the research outcomes to different audiences. This was done by the elaboration of a scientific master thesis manuscript and by the creation of short tutorial videos on how to use the app (Figure 4).

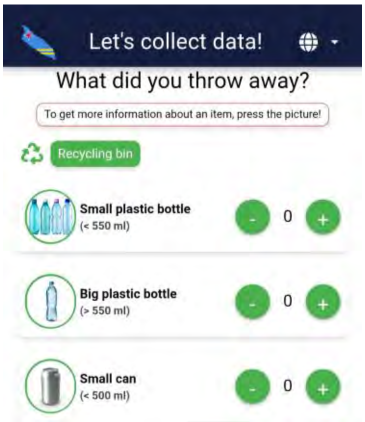

Figure 3: Screenshot from a section of the front-end of the developed app.

Figure 4: Screenshot from the video tutorial.

Learning outcomes:

The learning outcomes were measured by assessing students' skills such as autonomy, team spirit, communication, and critical thinking proven during the process, as well as the scientific rigour in the elaborated scientific manuscript and the oral defence of it. In addition, a semi-structured interview was conducted to students asking them to reflect and elaborate on their acquired skills and competences.

Students conducting an international research stay acknowledged that this experience helped them understand the contextual differences between their home country and Aruba. Technical knowledge on recycling was acquired through the site visit to the Aruban plastic recycling organisation, and a cultural understanding was obtained through interaction with students from the University of Aruba involved in the app testing. "*For cultural standpoint, it is interesting to see how people across the world think about certain issue, and here [Aruba] this is [waste] a really important issue so they really want to contribute"*.

The experiential learning approach applied in this case study, resulted in students learning to work independently. "*We learn from scratch how to do something, how to teach ourselves to do it*". Students believe this learning is an asset for becoming entrepreneurs "*We will work for our own, so for every problem, we will need to search for solutions, our own methods to face those problems*". In addition, the students believed that the setting of this project allowed them to develop a pro-active attitude "*We have to make something, but how we make it was up to us. So, we had the ability to learn things that we were interested in".* When interviewed on their acquired competences, the students highlighted hard skills, such as programming and learning about the architecture of a mobile phone application. Still, according to the students, the biggest learning is on project management, acquired by collaborating with different people. How this multidisciplinary project taught them to communicate with people from different backgrounds was identified as a valuable soft skill: *"For me it is very important for the future to have technical knowledge but to explain this to someone with less technical knowledge in this area, so still in a comprehensive way. I think it is a very important skill".*

The involvement of students from University of Aruba during the development phase supported local students becoming agents of change by participating in creating sustainability solutions. While workshops' participants were not interviewed, from the answers to the survey and open conversations during the workshops, a high interest in this project was perceived. The KU Leuven students giving the workshop quoted "*What I found really nice is that I really sensed that people wanted to change something in Aruba, and they were really motivated to use the app and give feedback to us".* In line with that, the value of making a contextually suitable mobile phone application that could support sustainable development was recognised*: "When we presented the app to them* [the students from University of Aruba]*, they gave a lot of ideas and solutions on how to make it more engaging for people in Aruba specifically. They were also thinking on how this could be good for having a better environment".*

Besides the students' learnings, this case study presents two additional major outcomes. First, it constitutes an example of how sustainability challenges can be targeted through citizen science at higher education institutions, bringing together students and academics from different disciplines. The presented approach can be replicated in future research projects to support sustainability transitions in SIDS, encouraging incorporating inputs from different faculties in the co-creation of locally applicable solutions. Next, the created app is expected to contribute to data collection which could provide insights into institutional waste production (when applied at the University campus) and national waste production (when used at household level). The app could potentially be applicable in other SIDS, constituting a tool for supporting sustainable waste management practices in the region.

3 CONCLUSIONS AND ACKNOWLEDGMENTS

In this contribution, two case studies have shown how education and research considering the specific characteristics of SIDS and the cross-cutting nature of sustainability transitions is applied through the SISSTEM programme. These case studies are not developed in isolation but are linked to SISSTEM bachelor and master theses, and to project-based bachelor courses. In this form, SISSTEM educates students in integrating the natural environment, technical, social, and economic aspects in engineering solutions. In addition to achieving academic goals, these case studies have led to initiatives that make the island more resilient. The Integrative Project course has resulted in numerous partnerships between institutions and the university, facilitating the creation of a locally applicable knowledge network. It has also supported institutions in their energy transition, which creates local examples on how to reduce dependency on fossil fuels. Creating the app tailor-made for the Aruban context provided the possibility of including user's needs and interests, resulting on a locally applicable tool to engage citizens in waste data collection.

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A CRITICAL APPROACH TO ENGINEERING MATHEMATICS FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT

Engineering projects are frequently experienced through the complexity of knowledge co-production between experts and local communities. This involves an ability to work critically and creatively within unfamiliar epistemologies, drawing from quantitative, social and scientific methods to realise high-impact solutions. In this work-in-progress paper, we put forward a prototype for a case-control study aiming to evaluate student buy-in and learning outcomes for a cross-cultural implementation of critical mathematics approaches contextualised by sustainability challenges. We outline and discuss aspects of mathematical modelling activities that can scaffold an environment where human subjectivity amplifies the quality and relevance of quantitative arguments. As proof-of-concept, we analyse exemplary work of first-year engineering students as they design, implement, and evaluate a model of population dynamics towards proposing solutions for the endangerment of a wild species. We then identify critical learning outcomes springing from the social and subjective context that envelops the processes of mathematical modelling, analysis and communication in the real world. Our initial results show that interdisciplinary sustainability-driven mathematics activities have the potential to empower students to adopt a conscious approach to societal and environmental challenges.

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1 INTRODUCTION

1.1 Knowledge Co-Production and the Connected Curriculum

Modern sustainability challenges are reportedly more effectively addressed when knowledge is co-produced between 'experts' and local communities. Research shows that high-impact engineering interventions are distinct for being context-aware, inclusive, goal-oriented, and interactive [1]. Knowledge co-production is built on the principle that the people affected by a certain project are the most suitable to evaluate its value and validity and sees non-experts as partners to judge the impact of an intervention. In practice, this involves modes of work that incorporate several ways of knowing in decision-making, planning and design. Given the fundamental character of mathematics within engineering, this paper aims at exploring the opportunities for knowledge co-production in the teaching and learning of engineering mathematics.

The challenges of uncertainty in engineering projects highlight a need for engineering education that enables students to navigate through unfamiliar epistemologies, drawing from a blend of scientific and social forms of knowledge to solve problems that can be transparently evaluated and continuously improved upon. Towards this end, the connected curriculum framework brings the idea that teaching can join different threads that had previously been considered to be unrelated, embodying public engagement as well as intellectual and ethical positions in education [2]. The aim of this connectivity is to embed an element of human complexity within day-to-day instruction, connecting the classroom to the wider world and communities around it. Similar ideas also underpin the provision of problem/project-based learning (PBL), where students learn through collaborative, self-motivated research and enquiry in solving authentic, open-ended problems. [3].

1.2 Sustainability and Critical Mathematics

Over the last three decades, a convincing argument has been made for mathematics education that is student- and community centred. Critical theorists [4,5] maintain that mathematics can be used in subjective ways to propose, sustain, or change ideas about society, economy or the environment. These pedagogies present mathematics as a creative process towards changing precarious realities, aiming to engage students in acting effectively against global challenges and to communicate quantitative ideas in an inclusive way. It is hence necessary to enable students to discover the transformative possibilities of learning mathematics to build a more sustainable world. This idea was first implemented in mathematics education for the empowerment of marginalized communities [4, 5], and has been more recently applied to present numerical evidence for arguments relating generally to real life problems [6-7].

Mathematics plays a hybrid, scientific and social role in engineering projects. Statistical mathematics and modelling can be used as a tool to systematically characterise, optimise, forecast or explain phenomena. Mathematics also plays a social role because it increases the potential of people to influence systems, processes or policies that bear direct impact on their life [5-7]. In this paper, we describe our initial efforts and experiences in designing and delivering activities that give students opportunities to reflect on how we can act more effectively via mathematical modelling.

1.3 Research questions

The rationale for the present approach to mathematics activities lies in that mathematical modelling can help students crystallise subjective ideas into “quantitative landmarks” upon which a shared understanding of a complex situation can be built [6]. This is a move away from mathematics education that is exclusively based on factual recall and routine procedures, instead opening up space for mathematics learning to be a dialectic exercise [5]. In this paper, we present mathematical modelling as a creative process, where mathematics can be communicated, evaluated, negotiated and transformed around the uncertain and non-ideal constraints of a real-life challenge. Therefore, the broad questions for this are:

- How can critical approaches to engineering education encourage students to communicate their ideas in the form of mathematics?
  - And more specifically, what are the synergies between a critical approach to sustainability education and the technical or abstract concepts in the mathematics curriculum?
- What are the lessons learnt across borders from exploring student awareness and empowerment in sustainability challenges via mathematics?
  - And more specifically, what are the features of student collaboration and exchange in sustainability-oriented engineering projects?

2 METHODOLOGY

2.1 Hypothesis-generating data

The hypothesis-generating data that motivates this study was sourced from summative student activities undertaken during the 2021-2022 academic year at a cross-disciplinary first-year engineering mathematics module. This module introduces students to engineering mathematics via collaborative case-studies exemplifying applications of mathematical concepts in science, healthcare, technology, and sustainability. For example, students are introduced to differential calculus by engaging with activities framed around the optimisation of family-run agriculture in the Global South and learn integrals by modelling non-invasive surgery protocols [8]. The course is delivered in a hybrid format, where passive activities such as knowledge acquisition are done online in preparation for staff-led workshops that activate student learning through hands-on mathematical modelling of engineering problems.

2.2 Activity Design

The source activity explored herein was themed around the endangerment of wild animals in Sub-Saharan Africa, through mathematical modelling of a finite-difference system predicting the evolution of subpopulations of pup (0 – 1 year), yearling (1 – 2 years) and adult (>2 years) animals [9]. In the activity brief, students were asked to propose solutions towards three important challenges for the survival of the species: (i) shrinking natural habitats, (ii) lethal diseases, and (iii) being hunted by local farmers. Final solutions to this activity were required to contain two discursive elements that should be based on the models and results obtained by students after performing numerical simulations. For this, students were encouraged to test their hypotheses via simulation-based cause-effect comparisons. This activity design intended to prompt students to make connections between mathematics parameters and empirical measurements, as well as mathematics-based action and their practical impact.

The activity design guided students through documenting factual mathematics knowledge such as assembling matrices and vectors, performing matrix-vector and matrix-matrix multiplication, or inverting a matrix. The main activity discussion regarded describing and comparing the effects of different survival probabilities on the total number of animals. The scaffold outlined below guided students as they chose on which subpopulation their proposed solutions should focus. These objective steps served as "quantitative" landmarks where students could validate their mathematical work against previously established criteria.

- The first landmark consisted of modelling empirical timeseries data of a wild species population as vectors that change with respect to time. This allows for assembling and solving linear systems of equations toward calculating survival probabilities of the three subpopulations of wild dogs [9].
- The second quantitative landmark was based on applying matrix multiplication toward deriving a forward/backward predictive model for each of the subpopulations of the species. This task relied on students using induction to assemble a forward system of difference equations with yearly time-steps. For backwards modelling, students need to employ the properties of matrix inversion towards predicting past populations.
- After obtaining a mathematical model that is based on matrix multiplication, inversion, and matrix-vector operations, students were asked to implement computer code to perform a sensitivity analysis towards demonstrating the effects of the survival and reproduction probabilities on the total number of living animals of the species.

2.3 Identifying examples of critical thinking in student solutions

Although students were asked to use mathematics towards determining *what* is objectively important in this challenge, such as the survival of wild animals, they were also prompted to discuss *how* this could be done in sustainable, systemic or humanizing ways. As an additional step, students were asked to give examples of realistic and feasible interventions that could result in the preservation or repopulation of the species. This activity component was included intending to steer students away from impersonal engagement with mathematics in favour of a reflection on the impact of mathematics-based creativity and action in the real world [4,5]. Based on existing frameworks for the identification of critical consciousness and mathematical critical thinking [6-7], we discuss three examples of critical thinking in student work:

- Recognising underlying assumptions in modelling and disclosing the possible limitations brought to results, contrasting and comparing different scenarios and evaluating their appropriacy as a mathematical solution (Examples 1 and 2).
- Communicating mathematical information in verbal or graphical form and vice-versa, explaining mathematical relationships and proposing analogies with real-life processes or systems (Example 2).
- Proposing sustainable and humanising solutions that are based on quantitative information obtained via mathematical modelling and that consider diverse value- and belief systems (Examples 3, and 5).

3 ANALYSIS OF STUDENT DISCOURSE

The exemplary evidence presented below was extracted from student work conducted as part of a previous study in the activity described in section 2.2 and is reproduced herein with the consent of the authoring students. These solutions were not evaluated based on their real-life feasibility, but rather on whether their underlying discourse was synthesised by a blend ethical and sustainable principles to objective mathematics reasoning. The content of student proposals submitted to this task ranged from a frequent attention to mathematical accuracy to a distinctive life-preserving care for people and the environment.

Example 1. Explicitly stating the underlying assumptions of a model:

> *[…] Firstly, it was assumed that the rates for survival and reproduction are the same across years, without any probabilistic variation. […] Change in the local climate, the presence of food and predators, or humans, can occur over the long term; if any of these events have significant impact on the rates, the model would not be able to take them into account.*

In Example 1, the student chose to focus on the validity of the mathematical model proposed in [9] when it is used under the assumption that the survival and reproduction rates of animals are time-independent. In this case, the real-life application of mathematics facilitated the student's conceptual understanding. Example 1 shows evidence that the student was able to evaluate the model by proposing factors (climate, food, or predators) that cause the underlying assumptions of the model to fail. This example is distinctive in that the student did not assume that survival/reproduction probabilities were smooth functions or time, but rather the result of complex interactions between stochastic factors that can be difficult to account for. Most importantly, this example shows that the student was courageous in challenging the stability of mathematical definitions when applied to real life problems.

Example 2. Using modelling and analysis to identify avenues for transformation:

> *[…]the adult survival rate increasing would have the most positive impact on the final outcome after 50 years. This can also be understood in the light of the fact that adults are the only sub-population that carry on to the year after,*

whereas pups and yearlings either grow up and become part of another sub-population or die[…]

Ultimately, it may be impossible to adjust one rate by a specific amount (as was done in the modelling) while keeping the other parameters the same. The behaviour, survival, and reproduction rates are interlinked in a way that makes such a precise controlled intervention implausible. Nonetheless, the rates provide a target that, if achieved, would bring about the non-extinction (and even the repopulation) of the species.

In Example 2, the student held onto the realisation that mathematical models are simplified ways of understanding a reality developed in Example 1. Within this context, the student was able to perform numerical simulations with different parameters and concluded that increasing the chances of survival of adult animals would have the most beneficial effect to the total number of the population after fifty years. This conclusion was closely followed by a disclosure of the practical possibility of changing isolated parameters in the model, where the student recognises that it is often challenging to change single elements of survival in multi-parameter population systems.

Example 3. Humanizing intervention:

> *In real life, [the species] usually lives in pack. The older animals are in charge of the daily hunting while the Pups watches and learns [sic]. In the process of hunting, inevitably, sometimes the livestock of farmers in the area would become the targets. And sometimes, in protecting their livestock, farmers would kill the animal.*

In complex scenarios, such as the one explored in this activity, there is a risk that students take on an approach that is either hostile to locals or to the animals. Although logical, such argument would be limited in that it ignores any complexity in the local reality of human-fauna interaction. Example 3 highlights work demonstrating an ability to draw information from social and ecological sources to interpret an otherwise theoretical mathematical system. In this example we highlight evidence of humanizing approaches towards addressing the challenge. The student identified the importance of hunting for the survival of the species, but also noted the possible issues that arise from spontaneous human-fauna interactions. This discourse is distinctive because it does not seek to demonise either part in the interaction, but rather to objectively state that hunting is a survival mechanism for wild animals and that protecting livestock is also a self-preserving action taken on by farmers.

Example 4. Large-scale non-invasive interventions:

> *Rabies is a disease which severely affects the species as there is no cure for this disease once it's contracted and always results in the death of the animal (Student Reference 1, 2015). One possible method by which animals in an area could be protected […] is through the distribution of vaccines through edible baits (Student Reference 2, 2016). This method of vaccinating animals in the wild is efficient as a*

large area can be targeted and there is a little amount of interaction with humans.[…]

Finally, the student Example 4 highlighted that lethal diseases are a significant threat to the survival of wild dogs, and proposed methods of non-invasive vaccination against rabies through edible baits. The student argued in favour of their proposed solution by considering that an effective solution covers a large area and involves minimal interaction between humans and wild species, basing their argument on references to the literature that had been validated empirically in the past.

4 FUTURE DIRECTIONS

Here, we bring together an envisioned research design to investigate the cross-cultural perceptions of a connected curriculum for critical mathematics from the perspective of student buy-in and motivation when presented with sustainability challenges. This paper does not provide a comprehensive account of a completed study, but ought to rather be viewed as a layout of an envisioned research design, that is initially set forth for the purpose of exchange with the SEFI community.

4.1 Proposed research methodology

We envision to adopt a single embedded case-study design methodology [10] that takes place over two consecutive stages in two different universities, one in Europe and one in Africa. Within the overall study that explores student buy-in to an integrated mathematics framework is a comparative dimension that contrasts the two local case studies, each representing one context of instruction. Figure 1 summarises the overall methodology envisioned for adoption for this study.

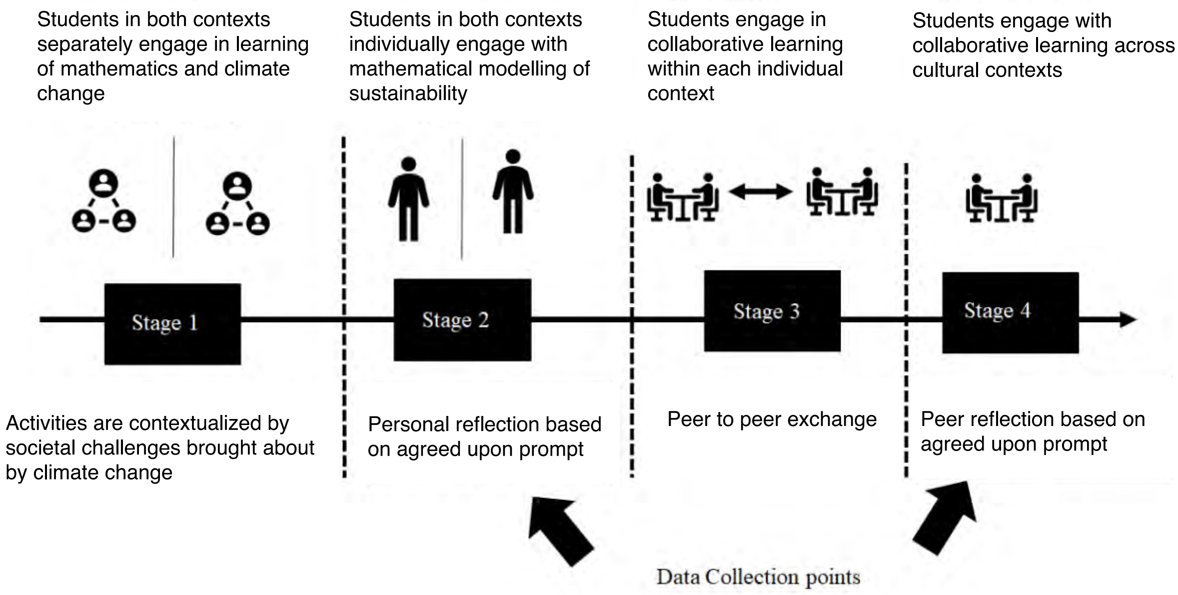

Figure 1. Data Collection Protocol

As presented in Figure 1, students from both contexts will take part in a series of sustainability-focused engineering mathematics workshops and activities in Stage 1. These activities aim to introduce students to critical approaches to mathematical modelling [4-7], sustainable development, and the social impact of engineering. Prompted by agreed upon reflection questions, participants are then encouraged to journal their perceptions about integrating questions of climate change into the mathematics curriculum. Students are prompted to reflect from the perspective of the relevance, complexity, and buy-in. In the second phase of the study, students are presented with an exchange platform that allows them to pair with a peer within their context to exchange experiences with. The peers are then prompted to document their reflections and exchange as guided by a pre-designed framework.

4.2 Proposed analytical framework

Findings from the first cycle of reflection are triangulated against each other and contrasted across the collaborating teams. Repeating patterns within each context are first recorded. This is followed by a cross matching of patterns across contexts. The final level of investigation also includes a triangulation element and a comparative element. Peer reflections are cross matched and re-occurring patterns are recorded. Peer reflection patterns are then cross matched against the individual reflection patterns. Figure 2 illustrates the analytical framework envisioned for adoption.

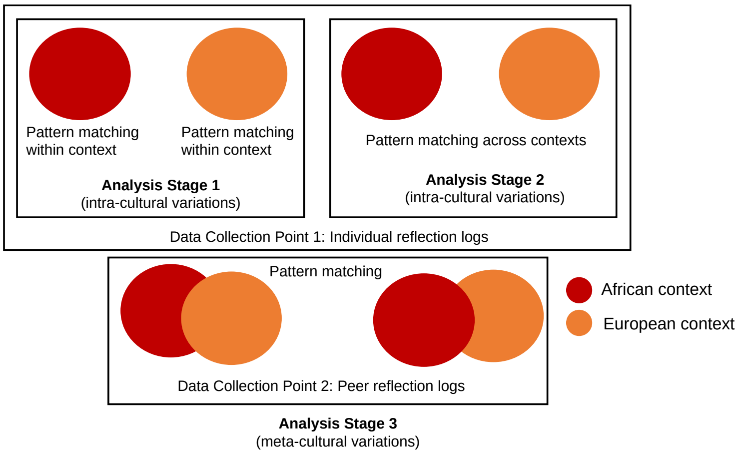

Figure 2. Envisioned Analytical Framework

The investigation therefore adopts an intra-cultural lens, exploring variations of patterns for student buy in within a given culture. It also adopts and inter-cultural lens, comparing variations of patterns across cultures. Finally, it adopts a meta-lens, exploring peer reflections and exchange across cultures.

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INSIDER ACTION RESEARCH ON AI NEEDS WITHIN THE EIT INNOENERGY ECOSYSTEM

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ABSTRACT

This practice paper describes an ongoing insider action research within the EIT InnoEnergy ecosystem. Its goal is to inspire teaching staff from the seven EIT InnoEnergy double degree Master of Science programmes to integrate Artificial Intelligence (AI) tools and knowledge into their courses based on joint learning. This insider action research runs from 2023 to the end of 2024. In late 2022, a problem statement of 'AI tools for Education' was identified by EIT InnoEnergy teachers as being crucial for their future learning and teaching processes. To align the needs of teaching staff with the complexity of emerging AI tools, a decision was made to plan a hybrid insider action research method. The outcome of this research will be two-fold: one resulting in an AI toolkit covering three teaching staff needs, and two getting a better understanding of the processes involved in taking up a learning innovation at different engineering partner universities spread across Europe within the EIT InnoEnergy ecosystem. This paper shares the first phases of the insider action research and an overview of the individual AI initiatives taken by teaching staff at different partner universities that is the result of a first qualitative data analysis coming from initiatives shared by the insiders (i.e., teaching staff). Action research methodology was chosen to inspire teaching staff to take an investigative and experimental attitude to the new AI technologies while allowing all actors to support each other and grow towards an AI integration in courses and curricula.

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1 INTRODUCTION

This practice paper shares ongoing insider action research with professors and teaching staff from the European Institute of Innovation & Technology (EIT) InnoEnergy Master programmes to integrate Artificial Intelligence (AI) tools and knowledge into their Master courses. Action research's distinctive characteristics are that it addresses the twin tasks of bringing about change in organizations and in generating robust, actionable practical knowledge, undertaken in the present tense in a spirit of collaboration (Coghlan & Holian 2023, p. 174).

The recent uptake of AI propels universities as well as societies into a new era of Society 5.0, where "Society 5.0 (Super Smart Society) is a new guiding principle for innovation" (Carayannis and Morawska-Jancelewicz 2022, 3449) in a complex system. Moreover, it gives rise to organic pedagogical models that embrace "freedom within flexible boundaries, richness of possibilities, interconnectedness of all parts of the system, and collective emergence" (Laroche et al. 2007, 74).
The rise of AI also adds an additional layer of complexity to collaborative actions. To ensure the complex texture of bringing together teachers from engineering universities across Europe on a mutually identified problem, a submethod was sought that would fit EIT InnoEnergy's ecosystem's complexity. Insider action research was the best fit. To limit the focus of this paper, only AI initiatives and tools directly used in teaching were investigated and analysed.

1.1 Supporting teaching staff in times of educational complexity

The EIT InnoEnergy Master School offers 7 double degree Master of Sciences (MSc) from top European technical universities and business schools, covering different areas: renewable energy, energy in smart cities, energy technologies, sustainable energy systems, smart electrical networks and systems, nuclear energy, and energy storage. All programmes are taught in the context of innovation, research, and industrial business strategies (van Rijsingen et al. 2023). The EIT InnoEnergy's education strategy and innovation team supports teachers in all partner universities with concrete, contemporary teaching designs and approaches that embrace both innovation and entrepreneurship aspects. In this context, AI knowledge integration happens in a collaboration between teaching staff and education teams set in a multi-university setting, all actors embrace "the importance of distributive leadership in developing a culture of trust and respect" (McGraw et al. 2021, 45). EIT InnoEnergy MSc programmes have the additional complexity of integrating real-world problems in its education through industry projects and challenges posed by industry partners and providing company internships for the students. This additional complex dynamic emphasizes the importance for a "close relation between a university competing internationally and its need to build global trust in the university" (Rosyidah and Rosyidi 2020).

When analysing the opportunities and challenges of AI in this context it was decided to approach this challenge from an action research prism due its suitability to build promotional strategies aimed at building trust (Bogacz-Wojtanowska et al. 2023) 182) showed that "action research projects can be directed towards". In addition, action research is particularly pertinent to current opportunities, issues and changing demands associated with a focus on the *Future of Work*, including sustainability and the natural environment, use of artificial intelligence technologies, and flexible employment (Delany 2022). Moreover, Coghlan et al. (2014) conclude that adding the competency (knowledge and skills) to design, facilitate and lead change by means of insider action research provides added value.

With EIT InnoEnergy particular context, one of the most attractive features of action research was its focus into the opportunity to learn with and from others, through listening and attending, acknowledging differences and assumptions when they are addressing a worthwhile issue (Coghlan and Holian 2023, p. 174). Adding the insider's perspective (the teachers and teaching staff of different academic institutions as well as the educational team), allows all stakeholders to get a voice in the final outcomes of the research. An additional benefit of the insider action research as a method was that insider action research emerged as an important way of understanding and changing organizations (Coghlan 2019; Coghlan and Holian 2007; Coghlan and Shani 2015).

1.2 Emergence of AI within sustainable engineering

While classical engineering has been successful in producing efficient and reliable systems that meet prespecified constraints and prespecified standards of performance in prespecified situations (Mina et al. 2006), integrating AI in sustainable engineering courses has no established prespecified knowledge to base itself on. Due to generative AI solutions only emerging in late 2022, and changing at an immensely high pace, AI related projects need an “engineering approach capable of (1) connecting different areas of knowledge, (2) encompassing diverse aspects of sustainability, and (3) articulating conflicting realities. This approach should allow dealing with situations characterized by uncertainty, emergence, and incompleteness of knowledge and information” (Sigahi, and Laerte Idal Sznelwar 2022, 233) which fits within complexity theory. Moreover, “action research provides the opportunity to study living emergent systems due to the flexibility and adaptability of the research design” (Ollila and Yström 2020, 398).

1.3 Insider target population

The target population of this research is a cross-section of the teachers and teaching staff involved in the EIT InnoEnergy Master school programmes who want to integrate (more) AI into their courses and curricula (n = 32). An open call was launched to all the teachers and teaching staff who wanted to be involved, and it was decided to also keep the target group open, so that during the year additional teachers could join. This aligns with one of the contexts of the insider action research contribution to developing a theory of what really happens in our ecosystem when a new innovative learning tool is taken up.

2 METHODOLOGY

When the complete member base of an organization seeks to inquire into the working of their organizational system to change something in it, they can be understood as undertaking insider action research. (Coghlan & Holian 2023). The context of insider action research is the strategic and operational setting that organizational members confront in their working lives. (Coghlan & Holian 2023). This is actually the case with the emergence and need for including the new AI opportunities within engineering courses and curricula.

The context of insider action research is beneficial within an umbrella organisation consisting of multiple educational partners such as EIT InnoEnergy, since (a) they are real events that must be managed in real time, (b) they provide opportunities for both effective action and learning, and (c) they can contribute to the development of theory of what really goes on in organizations (Coghlan & Shani 2015). The latter option of understanding what really goes on in our teacher organisation allows us to work on a long-term strategy to implement educational change more easily for future learning innovations.
Late 2022, a voluntary group of teachers and teaching staff replied to a call from EIT InnoEnergy's education team on what the teachers found to be their main learning and teaching problem. The teachers and teaching staff identified the problem area as: the understanding, evaluation, and uptake of AI tools by us - teaching staff - to optimize courses and curricula for EIT InnoEnergy Master programmes, in short AI needs in education. This would become the central topic of collaborative research.

As an additional challenge for this research, some of the teachers started experimenting with AI tools and services already. This meant, the group needed to share and discuss relevant data (e.g., first initiatives, research including AI…) of existing AI initiatives within the EIT InnoEnergy university ecosystem, to plan a collaborative action for stimulating AI knowledge and integration in education, as well as in the entrepreneurship journeys. Luckily, action research is a cyclical process, enabling immediate and ongoing optimisation and joint learning. It also allows the researchers to be actors, triggering additional practices and providing an active collaboration with practitioners (Ollila and Yström 2020). With the problem identified, a research initiative was started in January 2023 and running up until December 2024.

2.1 Action Research within sustainable engineering

The collaborative experience derived from an action research process is "designed to inspire an investigative, experimental attitude towards one's own professional practice beyond the organisation of data and the writing process" (Feldman et al. 2018). Thus, a space to share and build on all the teaching staff's experiences regarding AI was created in the form of insider action research. Ensuring a dialogue between all the actors of the target population throughout the research. This motivated EIT InnoEnergy teaching staff to reflect on integrating AI meaningfully in their courses based on the experience. Wood and Butt (2014) emphasised that "all voices are heard and engaged with as new patterns of being emerge". This is why all interested teaching staff was and is invited to instigate or participate in the new AI projects that we research as "action research can offer a positive medium through which to develop emergentist curricula, learning, and assessment approaches" (Wood and Butt 2014, 25).

Insider action research enables to follow the living, emergent system of integrating AI, while providing a research design agile enough to respond to events within our EIT InnoEnergy teaching staff network to create opportunities for joint learning. Thus, the actions, outcomes, and development paths were not planned. Instead, we followed the design as described by Ollila and Yström (2020), stating that actions "emerged as we followed the matters of genuine concern in the collaborative setting" (p. 402).

2.2 Gathering first data: mapping existing AI initiatives

First insights emerged through the continuous dialogue between EIT InnoEnergy teachers and the educational team during educational meetings. As mentioned, the problem statement emerged during a Teacher Conference late 2022. From there, an online dialogue was set up between all interested teaching staff. That dialogue comprised of sharing existing initiatives, as well as emerging challenges, and wish lists regarding necessary AI tools. Aligned to this dialogue between interested teaching staff, the EIT InnoEnergy Teaching Staff newsletter was used to disseminate the existing AI initiatives, as well as the emerging questions that arose. This was done to keep an open, welcoming mindset, allowing other teachers to join the ongoing insider action research.

This understanding enabled the educational team to act flexibly while concretizing the action research cycles of: identifying a problem area, gathering relevant data (e.g., existing AI initiatives – see list below, emerging problems), interpreting data (e.g., teachers identified wishful AI lists, that data was analysed to find patterns), acting on evidence (e.g., re-entering any conclusions to the dialogues), and evaluating outcomes (e.g. if a need for special AI tools were listed, was that in alignment with the needs of more than one teacher). This flexibility includes the continuing "spiral of action research cycles that emerge from the interventions, reflection, and learning after each cycle" (Ollila and Yström 2020, 398), within the overall research design agreed upon with the InnoEnergy teachers to support them with AI tool awareness and integration.

One of the first dialogues on AI tools that happened after the indicated problem, was on identifying the major strands for investigation. A question was launched to all the volunteering teaching staff (n = 32), asking them to share which type of AI support they were interested in. That resulted in three main AI categories:

1. AI tools to support administration (e.g., reporting, proposal writing),
2. AI tools enabling research activities, and
3. AI tools that could be embedded in pedagogical approaches for teaching and learning within engineering for sustainable energy.

During spring 2023, all the existing AI initiatives across the technical partner universiteis of EIT InnoEnergy were mapped. These initiatives were then analysed by all insiders, and reflected upon in group to see whether any of these initiatives would be useful for other members of the teaching staff. The initiatives shared were:

- Learning Analytics projects focused on analysing learner data from courses from the MSc school to inform and improve learning design using AI.
- EIT InnoEnergy teachers' experiments with AI and ethics within their Master courses (ethics, as well as energy and sustainability).
- Initiatives to integrate more digital skills in the curriculum in the form of Data Science and AI courses where students work on real energy problems analysing big data sets and developing e.g., predictive models

(https://www.linkedin.com/pulse/importance-active-learning-data-science-education-empowering/).

- EIT InnoEnergy research on the impact of using AI-generated synthetic video in an online learning platform on both learners' content acquisition and learning experience. A mixed-method approach randomly assigning adult learners (n=83) into one of two micro-learning conditions, collecting pre- and post-learning assessments, and surveying participants on their learning experience. The results show no significant differences in how learners perceived the traditional and synthetic videos (Leiker et al. 2023).
- Projects using AI technology based on Natural language Processing (NLP) to extract AI and sustainable energy skills from job offers, CVs and energy job market reports and be able to map skills to courses available on the market [4].
- And several teachers' exploration of AI tools for several teacher activities (resulting in the 3 identified AI strands to investigate).

From the perspective of the teachers of the individual MSc programmes, we learned that the emerging generative AI presented many new opportunities and insecurities to EIT InnoEnergy's multi-university teaching staff.

3 EMERGING TOPICS AFTER FIRST FULL CYCLE FINDINGS

After following a first cycle of action research: identifying a problem area, gathering the first relevant data coming from the insiders, interpreting that data, acting on evidence, the group had an evaluation after this first cycle. From the discussions three major topics emerged which would be re-entered into the group to set off the next cycle of action research: generative AI and AI tools within our entrepreneurial journey and courses, and emerging AI questions coming from initiatives.

3.1 Generative AI, strategy towards ChatGPT

To create a consensus on how to look like a group to ChatGPT and consequent strategies to take it up or limit its use, an activity needs to be planned where the impact, opportunities, and challenges of ChatGPT4 can be analysed by the group. Ever since the launch of ChatGPT to the wide public late 2022 and the proliferation of other generative AI tools, there has been an explosion of reactions in the education world. Different attitudes could be observed amongst educational institutions that can be categorized, as Philippa Hardman (2023) put it in a TEDx talk, as either dystopian or utopian, with a team "Avoid", trying to keep the technology out of the classroom, team "Ban" convinced that students should be forbidden to use the technology and that plagiarism detection needs to be put in place, and finally team "Embrace" emphasizing the opportunity it brings for the enhancement of educational practice.
Following the words of Saçan, "distrust towards chatGPT is a bad quick fix" (Saçan 2023, 2), and it is our believe that schools and educational institutions should encourage its' exploration so teachers can evaluate and compare uses and potential benefits.

[4] https://aiskills.innoenergy.com/

3.2 Exploring the options of AI within entrepreneurship journey and collaborations with startups and companies

The development of AI tutors and mentors is an area of increasing relevancy for education in general and for entrepreneurship education specifically. Very current examples are Khanmigo[5], a learning tutor embedded in the Khan academy and Yoodli[6], an app giving live feedback on presentation/sales pitch skills. In addition, companies launch AI tools in which ChatGPT 4 makes all business decisions for them (Santos 2023). While adopting such AI tools, teachers must ensure that students understand the impact of decisions based on AI, especially for entrepreneurs who influence society through various economic innovations. Action research incorporating joint learning across teaching staff towards future entrepreneurs is a necessity.

The engineering MSc programmes of EIT InnoEnergy also have an entrepreneurial side to them. Which meant that some of the insiders (business teaching staff) were emphasizing the growing effect of AI in business and entrepreneurship, and the need to explore these applications. AI is revolutionizing the way entrepreneurs are working and the way entrepreneurship can be potentially taught. McKinsey (2022) pointed out that generative AI and ChatGPT-like applications are taking assistive technology to a new level, reducing application development time, and bringing powerful capabilities to nontechnical users. We are already seeing examples of early-stage development of applications in areas such as marketing and sales, operations, IT/engineering, risk and legal or R&D. Specifically in the world of entrepreneurship, we now see public and private investor efforts to use StartupRadar's[7] data and OpenAI[8] to create embeddings, numerical representations of a startup, that allows for quick identification of similar startups (Lorey 2023), tracking of startup performance or tracing of most promising entrepreneurs.

3.3 Emerging AI questions

The ongoing conversations with the insiders, resulted in emerging AI questions containing practical AI use cases for energy engineering education, focusing on opportunities and value increase, while keeping an eye on risks and educational quality:

- Can generative AI tools automate course production such as video creation, content translation and assessment generation reduce the workload for teachers aiming to convert their courses to flipped classroom designs?
- How can students be allowed to use tools like ChatGPT or ChartGPT, for generating code and data visualizations in a way that supports the development of their coding skills?
- How can teachers encourage students to try out tools like ChatGPT to support them as a personal coach in their learning process and assist them in their writing assignments?
- How can teachers use chatbots to support their work such as the creation of lesson plans and generation of good coaching dialogues?

[5] https://www.techlearning.com/news/what-is-khanmigo-the-gpt-4-learning-tool-explained-by-sal-khan
[6] https://app.yoodli.ai/
[7] https://startupradar.co/
[8] https://openai.com/

- Can AI help to trigger ideas and brainstorming, or even create mock-ups for an innovative digital product (see for example [1 AI tool that designs in 1 minute!]).
- How can AI tools support Innovation & Entrepreneurship education, i.e. the more creative processes - traditionally identified as humans' advantage over computers - of ideation, synthesis, customer need validation, product building, and slide creation or pitch structuring for student presentations? How can the tools then be used to **augment** human intelligence and **not replace** human intelligence (De Cremer and Kasparov 2021)?

4 SHARING PRELIMINARY RESULTS AND NEXT ACTIONS

To address the emerging issue of Generative AI, AI in the entrepreneurial journey as well as in education in general, the educational team of EIT InnoEnergy planned an in-person workshop in the autumn of 2023, dedicated to:

- Understanding of the risks and opportunities of generative AI
- Launching an AI toolbox for all teachers
- Adding a focus on AI for its use in entrepreneurial education

Which will lead to the next cycle of the action research aligning it with the spiraling aspect of it described by Ollila and Yström (2020).

5 PRELIMINARY CONCLUSIONS AND ACKNOWLEDGMENTS

Although the action research is ongoing, some first conclusions were captured. A more in-depth understanding of generative AI is necessary, a closer look at entrepreneurial use of AI is requested and needed, and from exploring and sharing AI experiences more AI questions emerged to be addressed. These first cycle findings already highlight the empowering effect of working as a group of insider action research. Not only do the individual contributors grow their understanding of AI, but the group is taken to the next level of understanding by mutual inspiration. Next to redefining foundational knowledge within the teacher group, the skills and attitudes needed to perform key engineering tasks, as well as new skills must be integrated into university programmes.

5.1 Next steps

On 14 September 2023, the next in-person gathering takes place to follow up on this insider action research project. During this workshop, the full AI landscape (including ChatGPT) will be introduced by an AI expert to increase our mutual understanding and discussed by all present to align with the insider action research method. In addition, an AI toolkit will be presented and tested by actors of this insider action research. This toolkit will consist of AI tools useable for administrative purposes, for research support, as well as for teaching and learning (both engineering and business). Based on the outcomes of the workshop, the toolkit will be adjusted and finally disseminated to all EIT InnoEnergy teachers.

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TEACHING SUSTAINABLE LOGISTICS AS A PROJECT-BASED LEARNING COURSE

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ABSTRACT

Sustainable logistics combines the task of the 6R of logistics (right product, right place, right time, right condition, right cost) with social and environmental sustainability, especially low emissions and low resource consumption. This means that a problem that is already challenging, namely planning, executing, and controlling logistical processes, gets even more complex and requires aspects of systems thinking to incorporate environmental and social impacts. Classical approaches of teaching, e.g. lectures with presentations and short exercises on closed problems, do not do justice to the complexity and intricacies of the topic sustainability. In such a context, project-based learning (PBL) where students do group work on open-ended problems with real-world complexity seems to be a more adequate means to teach the subject. The paper describes a PBL course in which students worked on projects to conceptualize

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micro-depots for parcel delivery in different areas of Düsseldorf. A micro-depot is a temporary storage location in a city from which parcels can be delivered by cargo bikes. The aim was to locate the micro-depot, design the delivery routes, check the feasibility, and calculate the reduction of greenhouse gases and other emissions. The course was taught in cooperation with a partner from the courier, express, and parcel delivery industry. The paper describes the experiences with the course and gives recommendations for a successful implementation of PBL in courses on sustainability.

1 INTRODUCTION

1.1 Research motivation

Students in industrial engineering learn the basics of logistics in diverse courses such as production management, supply chain management, or operations management. Logistics typically includes the functions of transportation, warehousing, and packaging as well as the processes of purchasing, production, distribution, and reverse logistics, i.e. return and disposal logistics (Deckert 2017, 58-59). The planning, execution, and controlling of logistical processes is usually challenging and complex enough for students and in a classical context does not include considerations of sustainability.

Sustainability adds another layer of complexity to logistics and also forces students to include aspects of systems thinking to incorporate environmental and social impacts. Classical approaches of teaching, e.g. lectures with presentations and short exercises on closed problems, do not seem to do justice to the complexity and intricacies of the topic sustainability. For an elective course on sustainable logistics it was decided to use project-based learning (PBL) where students do group work on open-ended problems with real-world complexity since this approach seems to be a more adequate means to teach the subject. The project task was to conceptualize micro-depots for parcel delivery in different areas of Düsseldorf. This article reports the experiences with PBL in teaching sustainable logistics and gives tentative recommendations for further courses.

1.2 Theory of project-based learning (PBL)

Project-based learning (PBL or PjBL) can be understood as “an inquiry-based instructional method that engages learners in knowledge construction by having them accomplish meaningful projects and develop real-world products” (Guo et al. 2020, 2). Typical characteristics of project-based learning are a driving question, autonomous inquiry and active investigations, collaboration in a team, realism of the problem, and development of a functional solution, usually an artefact such as a prototype or a report with recommendations for action (Kokotsaki, Menzies, and Wiggins 2016, 268; Krajcik and Blumenfeld 2005, 320-328). These characteristics are mainly derived from the fact that students work in teams on a concrete real-world project with different tasks.
According to the PMBOK Guide by the Project Management Institute (PMI) a project is a “temporary endeavour undertaken to create a unique product or service” (Project Management Institute 2021, 4). This means that projects typically have a start and an end, different distinct phases, and a clear and novel goal. Typical features of a project, thus, are time limitation, complexity, uniqueness / novelty, and a distinct set of goals. Such a challenging problem typically leads to a high level of student engagement and motivation (Kokotsaki, Menzies, and Wiggins 2016, 268).

Project-based learning is sometimes grouped together with and in some cases even misunderstood as the concept of problem-based learning, especially since they both share the same acronym. It's true, that both are concepts of learning-by-doing based on autonomy, collaboration, and curiosity. However, there is a distinction between project-based and problem based learning: In project-based learning a well-defined project task is assigned to the team, while problem-based learning evolves around an ill-defined problem without many restrictions. Thus, project-based learning is usually experienced as being more authentic (de Graaf and Kolmos 2007, 5-6). This makes project-based learning especially suitable for learning in mechanical and industrial engineering.

1.3 Sustainable logistics and micro-depots

Sustainable logistics can be defined as the "application of principles from sustainability to logistics, i.e., the functions of transportation, warehousing, and packaging" (Deckert 2020, 1) and includes concepts of both Green Logistics and City Logistics. The task of logistics is the fulfilment of the 6R, i.e. to make the right quantity of the right product available at the right place and the right time in the right condition for the right cost. Green Logistics complements this set of goals with a low resource consumption and low emissions (or two furthers R if you want: right resource efficiency and right emissions). City Logistics focusses especially on the supply of cities and urban areas with goods. Main targets are a low stress on transport infrastructure (e.g. less traffic jams and accidents) and low direct emissions (e.g. noise or particulate matter) (Deckert 2017, 58-64; Deckert 2021, 24-37).

A micro-depot is a temporary storage location in the city – usually a container or a swap body which is dropped off by a truck. From this temporary location parcels can be delivered by cargo bike to the final customers. The micro-depot is typically located at the center of gravity of the deliveries. The logic behind this concept is that it subdivides the last mile into a second last mile (transport of container full of parcels by truck from the depot of the company into the city) and a very last mile (transport of parcels by cargo bike to final destination) (see fig. 1). The transport to the final destination is called a loop which includes several end customer deliveries (Deckert, Stodick, and Hertz-Eichenrode 2021a, 272-273, Deckert, Stodick, and Hertz-Eichenrode 2021b, 550-552, Stodick and Deckert 2019, 237-238).

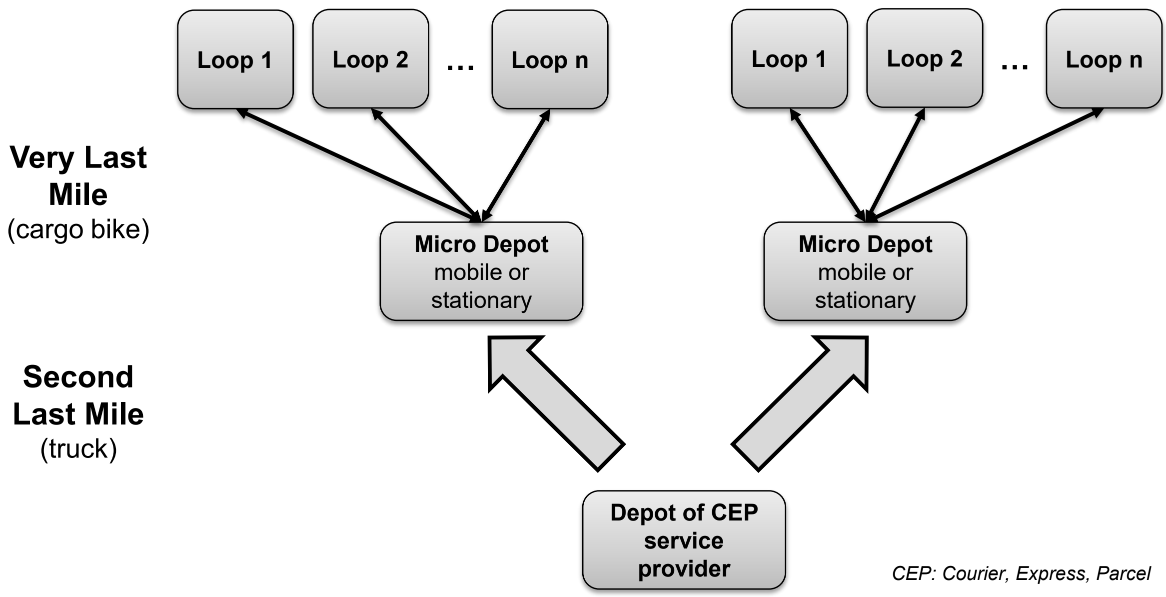

Fig. 1: Concept of micro-depots (Stodick and Deckert 2019, 237)

In this way, the micro-depot combines the advantages of transport bundling with the advantages of environment-friendly transportation and creates necessary conditions for the use of cargo bikes (e-bikes as well as conventional bikes), i.e. delivery of low volumes of goods over short distances. Current research on micro-depots shows that the concept has a high potential to reduce greenhouse gas emissions as well as exhaust fumes and to reduce the strain on the traffic infrastructure in urban areas (Deckert, Stodick, and Hertz-Eichenrode 2021a, 277-279, Deckert, Stodick, and Hertz-Eichenrode 2021b, 553-558).

The challenge to teach sustainable logistics is twofold. First, sustainable logistics is, up to now, not well integrated with classical logistics which focusses mainly on the classic goals of logistical performance (e.g. delivery time) and logistical costs already constituting a trade-off. To this, the dimension of sustainability is added which mainly deals with the externalities of a business and demands a systems thinking approach. Second, sustainable logistics also includes trade-offs between the functions of transportation, warehousing, and packaging, as decisions on the sustainability of one function influences the sustainability of the others (Deckert 2021, 38).

2 COURSE DESIGN

2.1 Target and tasks

As part of the course "Sustainable Logistics" at Hochschule Düsseldorf University of Applied Sciences, students had to work in groups on a project to design micro-depots for parcel delivery in different areas of Düsseldorf. The course was held three years in a row, each summer term from 2018 to 2020. A total of eight groups of three to five participants took part in the course, resulting in a total of 33 participants over the three years. The goal of the course was to locate the micro-depot, plan the supply to and from the depot, verify feasibility, and evaluate the reduction of greenhouse gases and other emissions (see fig. 2).

Fig. 2: Project tasks and sequence

In order to be able to evaluate the results obtained, a comparison was made between the emission output of the micro-depot delivery and the output of the currently implemented variant with delivery by diesel and electric vehicles. The course was conducted in cooperation with a partner from the courier, express, and parcel delivery industry who provided the real-world data to the students. A total of three delivery districts, or "loops" within the company, were defined as locations. The loop "Altstadt" is limited to Düsseldorf's old part of town, the loop "West" to the districts located west of the Rhine, and the loop "Hafen" to the southern part of the city center and the port region. The result of the course was a report with recommendations for action.

The research method of this paper is based on a mixed-method approach where qualitative as well as quantitative data are analysed. The qualitative data are based on the lecturer's perceptions and on an analysis of the final reports of the students. The quantitative analysis is comprised of the comparison of the grades and the course evaluations of the PBL course (2018-2020) with those of the same course with a written exam in 2022.

2.2 Outcomes

Locate the micro-depot

The first aim of the task was to find a suitable location for the micro-depot. The location was found by means of a theoretical and practical location determination. For theoretical determination, the parcel data provided to the students by the logistic partner were converted into individual coordinates using different geocode programs. These coordinates were then transferred to a location map. Next, seven of the eight groups determined the optimal location using the center-of-gravity method. One group determined the optimal location using the Steiner-Weber approach.

Following the theoretical determination, it had to be checked whether it is possible to set up a micro-depot at that location in practice. For this purpose, all groups visited the location to get an idea of the conditions on site. In doing so, they all found that due to various constraints such as pedestrian zones, unfavorable road layout, already developed land, etc., they had to choose a different location nearby in order to determine the practical location of the micro-depot. The geographical difference between the theoretically calculated optimal locations and the possible practical locations for the micro-depos identified during the site visits ranged from 0 to a maximum of 500 meters.

Plan the supply to and from the depot and verify feasibility

The delivery of parcels from the micro-depot to the customers is carried out by e-bikes equipped with an exchangeable box. The box has a capacity of max. 50 packages. Depending on the loop, a different number of e-bikes is required. To calculate the number of e-bikes needed, several factors were taken into account including the maximum working time per employee, the capacity of the box, the maximum range of an e-bike, the calculated distance to the customer, and the time per drop off. To calculate the possible trips per driver, the groups used various route planning methods. Mainly, the groups used the Sweep Algorithm, where clusters are formed first and then the route is determined. Two of the eight groups used the Nearest Neighbor approach for route planning, where the closest customer is served at a time until capacity is exhausted. Based on this planning, the number of e-bikes needed is four to eight e-bikes.

For the supply of the micro-depot, all groups decided to use trucks. The truck delivers the micro-depot in the form of a container. This container already contains the exchangeable boxes, in which the packages are pre-sorted for each tour. This means that the driver at the micro-depot only has to exchange the box as a whole and does not have to load each package individually. For certain deliveries that are impossible or difficult to handle by e-bike, for example, due to unsurfaced roads on which an e-bike can only travel to a limited extent, or when express or large deliveries are involved that require a quick turnaround or a large vehicle, five of the eight groups have designated electric vans for the tours in addition to the e-bikes.

Evaluate the reduction of greenhouse gases and other emissions

After completing the route planning, the students had the task of finding out whether energy consumption and emissions could be reduced by using the micro-depot. For the calculation of energy consumption and greenhouse gas emissions, DIN EN 16258 was used. In the first step, the transport performance was divided into individual legs. Then the energy consumption and emissions were calculated for each leg. In the final step, the results of all legs were summed up. For the evaluation of the carbon footprint, calculations were performed in the different variants of (1) standard delivery with diesel delivery vehicles, (2) standard delivery with electric delivery vehicles, and (3) delivery with the use of micro-depots and e-bikes. The result for all groups shows that when using the micro-depots, both greenhouse gas emissions and other emissions (e.g. exhaust fumes) are the highest for transportation with diesel delivery vehicles followed by delivery with electric vehicles. The highest savings can be achieved using the micro-depots.

All in all, the analysis of the outcomes from 33 students in the summer terms 2018-2020 shows that there was a high student engagement – as indicated by the self-reported motivation in the course evaluation and the attendance quota during lectures. No student failed the course, the average grade was 91% with a span of 77%-100% which is above average.

3 EXPERIENCES & RECOMMENDATIONS

3.1 Experiences

The experiences of teaching the course three years in a row show some advantages and disadvantages of project-based learning (PBL) which are mainly in line with what can be expected from the theoretical concept. The main advantages are as follows:

- PBL offers the opportunity to combine the theory of a subject with a practical part, e.g. the theoretical calculation of a center of gravity for a location and the practical search for an appropriate space for the micro-depot in the real world. This offers a deeper learning experience for the students, as they are forced to translate their findings into reality with all the related decisions necessary to accommodate for real-world restrictions. The combination of theory and practice in PBL also shows students the need for compromises in real-world situations. A theoretical calculation is never a perfect solution, as it is based on certain assumptions and cannot take all real-world restrictions into consideration. So students experience that there is no cure-all or silver bullet, but that theory gives good approximate solutions which can serve as a starting point for the practical solution. They also learn that there is no one-size-fits-all solution, again requiring compromises, e.g. some deliveries, especially big ones, still have to be made with a classical delivery vehicle, as they are not feasible with a cargo bike.
- In a PBL course on sustainability, students not only learn new methods (e.g. calculation of greenhouse gas emissions), but they also learn that standard methods of logistics (e.g. methods for vehicle routing) make a valuable contribution to sustainable logistics. It is the integration that matters.
- A project with interlinking tasks can only be solved through collaboration which means it requires a good deal of social interaction and a functioning team. Thus,

besides functional competence in logistics and sustainability, students gain social competence in a PBL course.

The main disadvantages of a PBL course in sustainable logistics are as follows:

- As PBL focusses on one specific project, students do not get a good overview over the topic (e.g. sustainable warehousing and packaging were not part of the course which focussed on micro-depots), and not all necessary methods and trade-offs can be included. So the breadth of knowledge which students acquire is rather limited. This contrast became clear when the course was taught to a larger group of students using a written exam as the method of examination in 2022: Students gained more breadth of knowledge but sometimes lacked in depth of understanding.
- A PBL course means more effort for the lecturer than a standard course. Main efforts occur in the design of the project, the preparation of the excursion to the industry partner, and the coaching of the teams. As the solutions to open-ended problems might vary, the grading also demands more instinctive feel than e.g. grading exercises or exams with closed problems. Furthermore, the success of a PBL course depends to a large part on the industry contacts of the lecturer.
- An important prerequisite for the students who want to participate in a PBL course about sustainable logistics is that they need to be well acquainted with the concepts and methods of classical logistics. The course only teaches sustainability aspects of logistics content-wise.

Student behaviour and feedback mirrored these advantages and disadvantages (as expected from the theory on PBL):

- In the three years when the course was taught in the PBL format there was a high student engagement and motivation. No student failed the course and the average grade was relatively high. Engagement and grades were distinctly lower when the course was taught with a written exam as method of examination in 2022.
- The students reported that they gained a deeper understanding through the course, but some criticized the lack of an overview over the subject or specific topics of interest.
- The course demanded social competence through team work due to the interlinking steps or tasks. The groups with the weakest team spirit – visible through bickering in the team or incoherence in presentation style – usually delivered the worst results and got the lowest grades.

3.2 Recommendations

From our experiences we generated three recommendations for problem design suitable for a PBL course. In accordance with the 6R of logistics we called them the 3R of PBL:

- Right topic: To get a driving question which motivates the students, the problem needs to be based on real-world data about an interesting topic and divided into interlinking tasks that force students to collaborate.
- Right partner: A realistic problem for a PBL course requires an industry partner who is willing to share data, talk openly about business intricacies, and give feedback on the students' solutions.
- Right limits: In the design of the problem there is a trade-off between realism and effort: The problem needs to be realistic enough to be motivating, but needs to respect the time and capacity limits of a semester course. Furthermore it

needs to be neither too specific for students to get lost in details nor too broad for students to lose focus. If the solution is implemented by the company, the damage potential of the solution needs to be kept low.

4 SUMMARY AND ACKNOWLEDGEMENTS

In summary it can be said that project-based learning (PBL) offers the opportunity for a deep learning experience of the students in sustainable logistics and significantly improves engagement and outcomes of the course. However, there are three caveats to be taken into consideration. First, there is a tension between breadth and depth of learning. PBL lacks in conveying the breadth of a subject. A combination of traditional courses with PBL courses would be an optimum solution, but often fails because of time restrictions. Second and related to the first point, when teaching sustainability there is the challenge of more and more additional contents which requires lecturers to re-examine their contents and set a new focus to keep within the time restrictions of a course. Third, up to now there is no real integration of classic and sustainable logistics which are usually taught in separate courses. This shows that sustainability – important as it is – is still often perceived as an add-on to classical logistics. Time will tell if such an integration will be possible in the future.

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LESSONS FROM REDEFINING TRADITIONAL WORK PLACEMENTS FOR UNIVERSITY STUDENTS IN TU DUBLIN

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ABSTRACT

There is strong support for ensuring all university students have an option to undertake relevant work placement. Work-placements enable students to engage with enterprise and develop experiential learning while linking their academic study and theory to real industrial practice. Such placements, or internships, offer students an opportunity to build their self-confidence while refining their transversal skills such as creativity, innovation, communication, team-working and problem solving. Furthermore, placements broaden students' knowledge base and improve their employability upon graduation.

While student cohorts benefit from engaging with enterprise the enterprise also benefits, such as from the energy, new perspectives and ideas interns can bring to the workplace. Multiple models (such as professional apprentices and Earn and Learn models) highlight the importance of this symbiotic relationship. The need to support

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and expand work placement opportunities to benefit all graduates is also a key element of government policy. Supporting this ambition and reflecting changing student profiles, employer expectations and the nature of work, there is a need to re-imagine the traditional understanding of work-placements to safeguard talent pipelines and increase graduate employability.

A concise literature review of existing work placement models is presented. This is followed by a description of the approach developed by the Enterprise Academy within Technological University Dublin to help students achieve learning outcomes typically associated with work-placements in a new, innovative and sustainable way. The approach described was successfully piloted for 2 student cohorts during the Covid pandemic. It highlights the value of redefining traditional placements for students, enterprise and higher education providers.

1 THE IMPORTANCE OF EXPOSURE TO ENTERPRISE AND WORK PLACEMENTS FOR GRADUATE FORMATION

Exposure to enterprise is crucial for university graduates as it provides them with the opportunity to apply and refine their academic knowledge while simultaneously gaining real-world experience. This exposure equips graduates with practical skills and knowledge that are highly relevant in today's competitive job market. More specifically, graduates develop transversal skills in areas such as project management, teamwork, creativity, communication, problem-solving, and critical thinking, which are highly sought after by employers. This practical exposure also helps graduates to understand how businesses operate, including their structure, processes, and challenges. Furthermore it provides them with a realistic understanding of the working world and instils confidence in them regarding how they can successfully interact with it.

The importance of work experience and how it provides graduates with key practical, transversal skills to help them bridge the gap between academia and the real world, enabling them to become well-rounded professionals, is recognised. In doing so graduates expand their professional network, and cultivate an entrepreneurial mindset. Giving students the opportunity to engage in work placement also aligns both with Irish Government policy [1] and the advice from professional bodies such as Engineers Ireland, highlighting the need for universities to prioritize providing opportunities for exposure to enterprise as part of students’ formal education. Section 2 summarises existing approaches to work placement from the literature and the need for alternative approaches. Section 3 describes the way that we re-imagined work placement and piloted it during Covid. Section 4 summarises the results of our impact analysis and summarises the lessons learned from our pilots. Concluding remarks are presented in Section 5.

2 LITERATURE REVIEW: THE NEED FOR ALTERNATIVES TO TRADITIONAL WORK PLACEMENT

The key concepts of Work Based Learning (WBL) where learning occurs in the work environment, and Work Integrated Learning (WIL) where learning is intentionally integrated with the practice of work, are differentiated in the literature [2]. Placements, where students are physically based in the workplace for a specific time period, have traditionally been the most common approach for fostering engagement between enterprise and education. This traditional work placement model may not be accessible to all students, particularly those facing financial constraints, geographical limitations, or other personal circumstances. Work placements can also be concentrated in urban areas, making them inaccessible for students who live in rural or remote regions or who might find it difficult to secure appropriate and affordable accommodation away from their usual place of residence. Business cycles can also limit the number of work placement opportunities available at certain times and this risk must be mitigated and alternatives considered.

Considering the shortfall of opportunities for placements and internships and factors that impede some students from committing to being physically based in the workplace, there is a need to explore alternative approaches [3,4,5]. Increasing attention has therefore been given to alternative formats which fall under the umbrella term of WIL, namely, hackathons, simulations, role modelling, site visits, enterprise projects and other experiential learning projects that prioritise the development of discipline-specific competencies related to professional practice and transversal or soft skills [2,3,4,6,7]. WIL intersects theoretical and practice learning and essentially brings real world work experiences into the classroom. It encapsulates the broad spectrum of enterprise-student engagement practices [7]. These new models can provide opportunities for students to work in cutting-edge industries, emerging fields, or unconventional career paths where opportunities available might align more appropriately with students' interests or expectations.

Whether it is WBL or WIL, the value is evident and is outlined extensively in the literature [3,4,7,8,9]. Benefits include the development of employability skills and work readiness [2], the fostering of career managing competencies such as professional networking, labour market understanding, informed career goals [8] and advancing transversal skills such as teamwork, problem-solving & decision-making.

The basic premise for both WBL and WIL is that not all skills can be learnt in the classroom or workplace but through a combination of both [2]. Affording students the opportunity to interact with different practitioners in a company though WBL or WIL initiatives requires a sophisticated level of both technical & non-technical skills [6]. Through the provision of authentic learning experiences to students across their learning journeys, the goal is to help students successfully and confidently transition to work. Having an increased clarity of their career expectations will improve their chance of success upon graduation.[3,4]. Such integration of theory and practice to directly support students' career readiness is a powerful learning approach [4]. Work-based experiences are essential to prepare students for the real-life context of their professional practice [6].

Students value the opportunity to engage with enterprise and develop an understanding of their proposed career through both traditional and non-traditional placement experiences [4,8]. Students cite the value of working with others and having unique experiences focussed on work related tasks as key to success when entering the workplace [10]. The more holistic approach is deemed necessary to ease students out of their comfort zone and face the emotional challenges within the work environment [10], helping students refine their transversal skills. Upon completion of a WBL or WIL programme, students reported the benefits of having an increased ability to identify their capability gaps and better synthesise their strengths and motivations [8].

The literature highlights that students require more WIL opportunities as they realise the benefits in terms of both skill development and the fact that practical experience is such a high priority among graduate employers [3,5]. The pilot programme discussed in section 3 addresses this and confirms the positive impact of WIL for all students.

Graduate employability is one of the fundamental issues influencing the missions of Higher Education Institutions (HEIs) [6] and they strive to find ways to enhance student employability. The importance of adopting a more holistic and skills-based approach to developing employability is well documented in the literature [10]. The need to go beyond the skillset that can be taught and learnt solely in a classroom and adopt a more integrative approach to boosting employability is a top priority in HEIs [2,3,7,10]. Educational institutions, academics, employers, and even policymakers must consider alternative work placement options that provide students with more flexible, adaptable, diverse and potentially more inclusive pathways to gain real-world experience and enhance their employability.

Reedy et al. document a case study where engineering students embarked on a project oriented, problem-based learning (PO/PBL) WIL learning activity to increase their workplace awareness and boost their work-readiness capabilities [5]. Students were tasked with solving a unique enterprise challenge requiring both technical and non-technical skills for its resolution, meeting with both enterprise and academic mentors weekly to discuss their progress [5]. The study revealed the value of this model for boosting students' professional identity, motivation and providing useful opportunities for students to develop employability skills in a supportive environment.

The Sustainable Innovators for Enterprise (SIE) programme documented here adopts a similar approach by facilitating a space for students to engage with the world of work via an enterprise challenge. The SIE programme prioritises the development of employability and transversal skills through the lens of a global, cross-disciplinary enterprise challenge with an international dimension. It supports the need for more innovative and sustainable models to ensure students receive meaningful opportunities to prepare for their future careers. The remainder of this paper details the SIE work placement programme, built upon research conducted prior to the Covid pandemic, that highlighted the need for such alternatives. This programme was piloted during the pandemic as an alternative to traditional on-site work placements.

3 STRUCTURE OF THE ALTERNATIVE TO WORK PLACEMENT PILOTS

The work placement programme was structured to mimic a traditional work placement which would meet the requirements of our existing programmes. This programme was available to students across the university and also to international students from Hainan University who are registered on TU Dublin programmes. Student interaction with the programme can be viewed as part of four key phases.

Table 1. Key program activities of program as piloted

Phase	Key Activities	Duration
Phase 1: Introduction SIE Onboarding	Innovation Onboarding Create Confidence Workshop STLR Training Introduction to Cultural Intelligence Enterprise Challenge Day	~ 1 week
Phase 2: Pre-immersion Enterprise Recruitment Kick- Off Session	Recruitment Training Indeed Workshop Indeed Live Hiring Event: Student Interviews for Enterprise Challenges You Got the Job! Student Teams Assigned TU Dublin & Enterprise Mentoring Kick-off Meeting	~ 1 week
Phase 3: Project Immersion Supporting modules Key Project stages (Innovation Lifecycle)	Innovation for Enterprise Global Citizenship in the Workplace Creativity & Human Centered Design Future-Proofing Talent 1. Empathy & Problem Definition 2. Investigate, Human Centred Research and Empathy 3. Ideate, Evaluate and Prototype 4. Build it and Test it 5. Iteration and More iterations 6. Implementation Part 1 7. Implementation Part 2	~ 10 weeks
Phase 4 Post-Immersion	Final documentation and pitch	~ 1 week
Innovation Conference		End of programme

a) Recruitment to a particular challenge

As part of Phase 1, each enterprise presented details of their company and proposed their challenge(s). Following this, students had an opportunity to ask some initial clarification questions relating to the enterprise and/or the challenges. Subsequently students applied to undertake a particular challenge. For Phase 2, the Enterprise Academy partnered with Indeed to pilot their Indeed Hiring Platform (IHP) to simulate a real-world recruitment process. The Enterprise Academy worked with the IHP team to design a recruitment process that was suitable for the student cohort. The enterprise challenges were then posted on IHP and students had the option to select their three preferences. Students then completed a pre-screening questionnaire to assist with determining their suitability for challenges.

The SIE design focused on immersive experiences whereby Indeed hosted an online hiring event over two days. Students were invited by Indeed for an online Interview through the virtual hiring platform. The programme team worked with Indeed to design specific questions and an interview style suitable for the student cohort. Indeed provided several trained recruiters who conducted one-to-one interviews with students. A matching algorithm was used to match the most appropriate students with the challenge most appropriate to their skillset, Students were then “offered the job”. The programme team, Enterprise Academy and Indeed collaborated to ensure each team was composed of the multidisciplinary skillset required for each enterprise challenge. This was part of a detailed process to help the students develop their own career readiness skills. Examples of activities covered include interviewing skills, self-promotion, and building their own profile on Indeed and LinkedIn.

b) Modules

This programme was assigned a total of 30 ECTS credits, matching traditional placement ECTS allocation. The breakdown of this was three five-credit modules and a fifteen-credit Enterprise Challenge module. The modules were co-created with enterprise and academic expertise. Each five ECTS credit module was designed to help students develop transversal skills and support their attempts to follow a systematic design methodology in responding to their design challenge.

Fig. 1: Overview of modules involved in work placement as piloted

Flexibility was designed into the approach to enable students from other programmes, or in part-time placements, to also take individual elements. For example, students who could only secure part-time placements completed the 15 ECTS to scaffold their experience. This modular and agile approach addressed a strategic goal of the university to create economies in module design and delivery.

c) Teaching approach

Each team combined students from TU Dublin and Hainan University resulting in an international, cross-disciplinary experience for all. The virtual exchange model provided an immersive global learning experience for participants bringing diverse students and faculty together across borders of time zones, language, culture and disciplines. The Global Citizenship in the Workplace module was co-created and delivered by faculty from Hainan and TU Dublin exposing students to culturally diverse teaching strategies and providing a rich insight into Chinese culture.

The Enterprise Academy advised on best practice for simulating an immersive work environment. The learning environment emphasised creating 'brave spaces' [11] that fostered creativity. Students engaged with a variety of professional tools such as Mural, Cultural Intelligence Self-Assessment, and strategies such as Wicked Problem Solving and Human Centred Design to facilitate an immersive work experience. Consequently, transversal skills such as wicked problem solving, Cultural Intelligence (CQ) and leadership were developed in a simulated a workplace training and development environment.

d) Role of academic and enterprise mentors

Each team was assigned an academic and an enterprise advisor or mentor to help and guide the teams through weekly meetings. The enterprise advisor was from the organisation who assigned the challenge and were able to answer questions from a customer organisation perspective. The Enterprise Academy partnered with Active Peers AI and internal educational developers to design the SIE mentoring process. Students were expected to arrange the meetings, set an appropriate agenda, take meeting minutes and actively manage the meetings to ensure that all questions that they had were dealt with and answered appropriately within the allocated time slot.

e) Assessment and deliverables

The supporting modules and the Enterprise Challenge were assessed separately and involved different deliverables. The Enterprise Challenge had formative and summative assessments. Students created a portfolio explaining their proposed solution and gave a live pitch to an assessment panel and answered questions in a formal question and answers session.

4 PILOT STUDIES: IMPACT ANALYSIS RESULTS AND LESSONS LEARNED

The two pilots provided insights from a student development and university enterprise engagement perspective. The programme team collected data and observations throughout the pilot design and delivery. Insights collected focused on informing the pilot design and the observations enabled the team to identify areas for student transformation. Prior to commencing SIE all students participated in an interactive workshop to self-identify their personal strengths and areas for development. These workshops utilised human-centered design (HCD) techniques and enabled the programme team to identify student concerns and areas for development. For example, in both pilots the interview process and confidence in collaboration were identified as areas of concern and as development opportunities. The lessons learned from the first pilot informed the next iteration and the recruitment process was evolved to ensure the students were supported and that the development opportunity was leveraged. Fig. 2 provides an example of the HCD technique Hopes and Concerns applied with the 2021 pilot cohort.

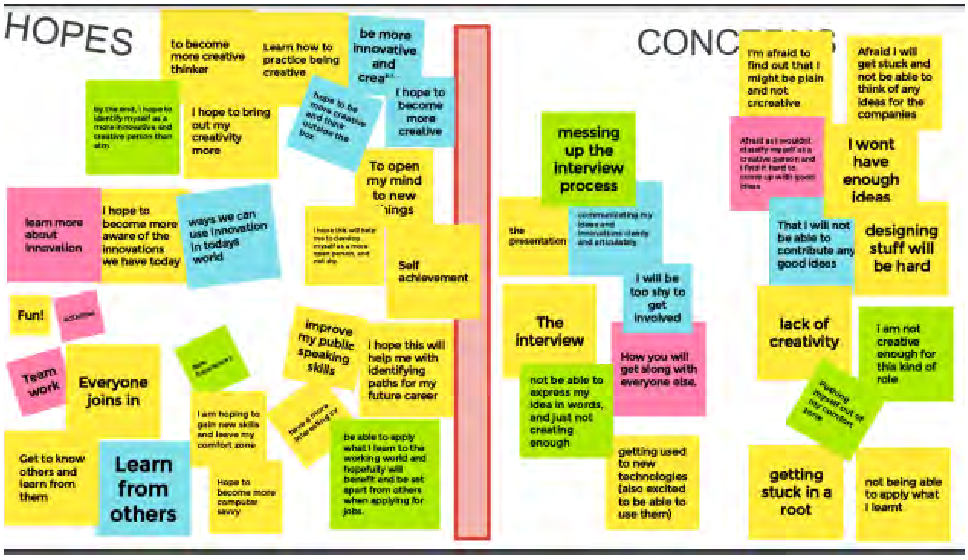

Fig. 2: Pilot 1 Observations 2021, Hopes and Concerns

The student feedback post-pilot presented insights that suggested a positive impact on student development and that SIE was successful in preparing students for the workplace. Table 2 lists a selection of responses demonstrating pilot impact.

Table 2: Positive Insights from Student Feedback

Question	**Response Rate**
I feel more prepared for the workplace	37.5% strongly agreed, 37.5% agreed
I feel more confident in my communication capabilities	50% strongly agreed, 50% agreed
I feel more confident in my team working capabilities	62.5% strongly agreed 32.3% agreed
Rate your experience of enterprise engagement on SIE	68.8% excellent, 25% very good
Rate your experience of the SIE mentoring programme	50% excellent, 37.5% very good
Rate you experience overall on SIE	Average of 4.19 out of possible 5

The main barriers identified for SIE were perceptions of *work placement alternatives* and *resource constraints*. The programme team observed that faculty and students viewed the 'alternative placement' as an option for students that could not secure a traditional placement. This view of SIE as a lower value experience would need to be further explored and the impact of SIE on skill development validated through a larger sample. The pilots discussed in this paper received funding to explore technology and professional resources to emulate the work environment.

5 CONCLUDING REMARKS AND FUTURE PLANS

There is strong support for ensuring that all university students have an option to undertake relevant work placement as part of their studies. The lack of accessibility, and potentially availability, of suitable work placements, can limit student opportunities and hinder their ability to gain practical experience. This will require universities to have alternative work placement model options available for their students.

These alternative approaches to work placement can encourage students to explore new areas of interest and can provide them with more flexibility and adaptability in gaining real-world experience while they develop unique skill sets. These new ways of learning and skill development will make them more competitive and adaptable in the ever-changing job market.

The world of work is evolving rapidly and new industries, technologies, and career paths are emerging while non-traditional work arrangements such as remote work, freelancing, and the gig economy are becoming more prevalent. Traditional work placements may not provide students with exposure to the latest trends and innovations, which could potentially impact their readiness for the job market

The lessons learned from this pilot and existing research suggest that students benefit from the opportunity to work in a multidisciplinary environment. Higher education providers have the opportunity to create these immersive environments. However, if the intent is for these environments to prepare students for the workplace then further collaboration with enterprise is needed. This collaboration has purpose for enterprise and can provide many benefits including, access to talent pipelines, insights and research.

There is a need for HEIs to reflect and ask the question 'how are we preparing our students for work?' The answer will require further collaboration with enterprise to co-create education offerings that reimagine the concept of ‘close to practice’ or 'approximations of practice' [12]. It is hoped that the pilot described here might contribute to the development of flexible and engaging alternatives for students.

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Problems without Solution? Challenges of Climate Change and Sustainability in Engineering Education

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ABSTRACT

The issues of climate change and sustainability are urgent and critical concerns of our time. The rise of climate disasters, such as floods, droughts, forest fires, and hurricanes, poses a threat to the survival of humans, animals, and plants. Despite scientists having warned about the impending dangers of high CO2 emissions, particularly from the global North for many years, there has been no political or technical solution in sight.

Engineers are known for being problem-solvers, but what happens when the problem is complex and the consequences of technical interventions are hard to predict? In my paper, I propose measures to sensitize engineers to the complexity of climate change and sustainability. Based on the method of focused ethnography, I draw on Feminist teaching methods, my extensive teaching experience in the field of transdisciplinary gender research in science and technology studies, and my observations during the international "Winter school of ENHANCE on gender and diversity in science, technology and society" at Technische Universität Berlin in 2023.

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The paper concentrates on the content and pedagogical approaches that can be used to convey the complexity of the issue while fostering the development of critically reflective knowledge. By incorporating these measures, engineers can be better equipped to tackle the challenges posed by climate change and sustainability in a more holistic and thoughtful manner.

1 INTRODUCTION

1.1 Climate Change and Engineering's Impact on Sustainability

Climate change has altered the Earth's climate system over the past two decades, resulting in long-term shifts in temperature, precipitation patterns, and extreme weather events. Greenhouse gas emissions from human activities, such as burning fossil fuels and deforestation, are the primary cause of climate change. These emissions lead to increased concentrations of carbon dioxide, methane, and nitrous oxide in the atmosphere, resulting in a warming effect known as the greenhouse effect. The impacts of climate change are severe. Over the past two decades, climate change has continued to intensify, leading to more frequent and severe extreme weather events and significant environmental impacts such as melting of glaciers and ice sheets, coral bleaching, and declining fish populations. However, there has also been increased awareness and action to address the issue, including the adoption of the Paris Agreement and measures to reduce greenhouse gas emissions and increase climate resilience.

In light of these facts, it must be stated that climate change poses a significant threat to the long-term sustainability of human societies and natural systems. Considering this, sustainable practices such as transitioning to a low-carbon economy, adopting sustainable energy sources, sustainable land use practices, sustainable transportation options, and sustainable manufacturing practices are crucial for reducing greenhouse gas emissions and ensuring the long-term sustainability of human societies and the natural environment.

Addressing climate change and sustainability in Engineering Education provides an opportunity to create a more sustainable and resilient future for people and the planet. Because sustainability and engineering are closely intertwined since engineers have a significant responsibility in designing and implementing solutions that advance sustainable development. With their knowledge and expertise, engineers can create technologies and infrastructures that minimize environmental impacts, conserve natural resources, and enhance social and economic conditions. Renewable energy technologies, such as wind, solar, and hydro power, are a crucial area where engineering can contribute to sustainability.

1.2 Gender, Diversity and Sustainability

Gender and diversity are important but nevertheless still under-thematized dimensions of climate change (Buckingham/Le Masson 2017). Not only are women predominantly engaged in the main energy-consuming tasks in the home, but gender and diversity also play a role at the sociocultural and technological levels. To this end, it is necessary to develop a broader perspective with respect to sustainability and to sensitize students to the (gendered) impact of their technological solutions. In the following, I list key points that have been largely ignored in technology research on climate change:

- A binary notion of gender makes it impossible to include queer, non-binary identity designs that cannot be easily categorized in adaptive designs. At the same time, queer people often live in areas threatened by climate change due to their social stigma.
- Intersectional analyses of the implementation contexts of technological solutions are indispensable to adequately consider the particular inequalities that for example affect women of color.

- Women, in particular from the global South, are often portrayed as victims in discourses on climate change. This perspective overlooks the fact that women form a heterogeneous group that is permeated by further dimensions of inequality. At the same time, the focus on women (from the global South) narrows the view.
- The important role that constructs of *white* masculinity play in determining individuals' carbon footprints is often overlooked.
- Studies show that women in leadership positions are responsible for implementing more sustainable solutions. However, most leadership positions are held by *white* men.
- At the same time, women are less likely to be involved in adaptation strategies and processes to develop technological solutions to climate change, as they are often unable to engage in participatory processes due to caregiving responsibilities.
- Technological solutions can profoundly change the lives of girls and women and, in the worst cases, help to re-stabilize asymmetrical gender relations.

As I mentioned elsewhere (Dornick, 2021), it is important to note that brief exposure to diversity and inequality issues may not sufficiently equip students with the ethical capabilities required to develop technological solutions for complex societal problems. To address this, Engineering Education should also aim to deepen students' understanding of power dynamics in society by teaching them about the gendered nature of technology and how power relations are manifested in material forms. The inclusion of gender and diversity skills in Engineering Education not only prevents exclusion and discrimination, but also promotes successful and sustainable engineering by rejecting individualistic approaches and the predominance of male professional cultures. To equip future engineers with the ability to address the intricate environmental, social, and economic challenges of our world, it is essential to teach sustainability in Engineering Education.

2 METHODOLOGY

2.1 Research Design

In the following I draw on the method of ethnographical observation. Ethnography is an approach to qualitative research that is used to investigate cultures and people (Flick 2007). It involves the systematic observation of social phenomena where researchers immerse themselves in the culture they are studying to gain an insider's perspective. Ethnography employs various data collection methods, such as participant observation, interviews, focus groups, and document analysis. The purpose is to gain a deep understanding of the culture from the perspective of those being studied, and to document the social and cultural practices and norms of the community. Ethnography is commonly utilized in disciplines such as anthropology, sociology, and other social sciences to study a broad range of subjects, including culture, social interactions, and power dynamics.

For the following study, I have oriented myself on the method of focused ethnography (Knoblauch 2001). Focused ethnography is a type of ethnographic research that focuses on a specific research question or phenomenon within a particular community or culture. It is often used when researchers have a limited amount of time or resources to conduct their research. Focused ethnography differs from traditional long-term ethnography in that it has a narrower scope and is conducted over a shorter period of time. The researcher may use a variety of qualitative data collection methods, such as interviews, observations, and document analysis, to gain an in-depth understanding of the specific phenomenon or research question. The findings from a focused ethnography study can provide valuable insights into the social and cultural practices of the community being studied, and can be used to inform future research and interventions. At present, ethnographic methods enjoy great popularity, especially in the social science-oriented areas of science and technology research, because they make it possible to take a detailed look at the practices of the making of reality.

2.2 Research Field

As a research field, I take as a basis my own extensive teaching experiences in the field of transdisciplinary gender research in science and technology, my observations during the international "Winter school of ENHANCE on gender and diversity in science, technology and society" at the Center for Women's and Gender Studies (ZIFG) at Technische Universität Berlin (TU Berlin) in 2023, as well as my analysis of learning journals of students in Engineering Education that had taken part in the learning module "Bue Engineering" at The Department of Machine Systems Design at Technische Universität Berlin (Dornick 2021). The main objective of "Blue Engineering" is raising awareness among students about their social and ecological responsibilities. This elective module has been available since 2011 and is worth 6 credits points in Mechanical Engineering, Information Technology in Mechanical Engineering, Transportation Engineering, Sustainable Management, and Industrial Engineering degree programs. Every semester, approximately 80 students participate in the four-hour seminar. Over the years, this module has been successfully adopted by other universities, including Hamburg University of Technology, Düsseldorf University of Applied Sciences, Berlin University of Applied Sciences, and Ruhr West University of Applied Sciences.

The faculty of "Humanities and Educational Sciences" at TU Berlin has a close association with the four faculties for technical and natural sciences, owing to the university's distinctive history (Profile "Humanities and Educational Sciences at TU Berlin", 2023). The ZIFG, following an interdisciplinary teaching approach, offers courses that are open to students from humanities and educational sciences, as well as technical and natural sciences. Students can earn ECTS points towards their BA and MA degrees or participate in specialized programs, such as "Gender Pro MINT" or ZIFG's gender certificate.

The courses observed in this study were taught by the author during the period from Winter term 2018 to Winter term 2023. The author mainly conducted participatory observations during class sessions. Evaluation was carried out during the last class of the term when each student provided oral feedback. The main focus of these courses was to enhance Engineering students' ability to act in a gender-sensitive and diversity-oriented way by deepening their understanding of intersectional forms of discrimination and co-constructive processes of gendering artifacts. The curriculum included topics such as Feminist philosophy and critique of science and technology, introduction to transdisciplinarity of gender studies in science and technology, gender, diversity and sustainability, and gender in Higher Education. Participants in the courses had diverse academic backgrounds, including "Engineering," "Computer Science and Design," "Culture and Technology," and "Gender Studies." The size of the classes varied from five to 35 participants. I consider both face-to-face and online courses. For synchronous sessions, the video conferencing tool Zoom was used. All sessions were assisted by an e-learning platform and, from 2020, also received support from various other online tools such as online pads, Wonder (a platform for working in working groups), Discord (a platform for meetings and chats), and online whiteboards (see Dornick 2020, for a detailed description of the module “Blue Engineering” and Dornick 2021 for a detailed description of my teaching practice).

3 RESULTS

3.1 Understanding Climate Change as a Complex and Multi-faceted Phenomenon

Let me start with an anecdote. In my presentation on Gender, Diversity and Sustainability at the international “Winter school of ENHANCE on gender and diversity in science, technology and society” at TU Berlin, I drew attention to the urgency of climate change and the need to take appropriate action to address it. The international students nodded, studied the overviews, and actively participated in the discussion session that followed. After a while, one student asked, "And what proposal do you have now for solving climate change?"

I resort to this anecdote for several reasons. First of all, because I was so surprised by the student’s question that this moment has impressed itself on me. Moreover, this anecdote seems to me like a vignette in which the difficulties and challenges of inter- and transdisciplinary understanding on climate change are revealed.

How on earth, I wondered, could students assume that one person, let alone me, a sociologist from Feminist Science and Technology Studies, could have found THE solution to climate change? But besides the naivety of the question, I also felt something like hope in that question. Hope, that there could be a solution, that it could be found, even that it had already been found. I looked into the room, which was filled with prospective engineers, and thought about what I should answer them. Was it perhaps a test question? Or was the question meant to provoke me? After all, I had criticized various engineering solutions. Could this question be serious? There were so many different levels to consider in developing actions on climate change. First and foremost was our understanding of climate change, of nature, of the survival of human civilization, followed by hypercomplex causal chains that constantly unfold as climate conditions change: Extinction of species, change of soils, loss of livelihoods.... I decided to put aside my fear and also my indignation and give a transformative response. I replied: “No, unfortunately, I must admit that I do not have a solution. It's even worse, I do not think there is ONE solution. Rather, I think there are many solutions and we must find them together. But, unfortunately, at the moment it doesn't look like all the energy is being put into finding solutions”.

Following on from this anecdote, I would like to emphasize that my teaching practice in Engineering Education has shown that it is essential for engineers to gain a more complex image of the world. That means, that, besides the social and ethical dimensions of technological issues, engineers that are concerned with sustainability need knowledge about *naturecultures*. Donna Haraway, a feminist scholar and philosopher, coined *naturecultures* to refer to the interconnectedness and interdependence of humans and the nonhuman world (Haraway 2016). Usually, "nature" refers to the nonhuman world and "culture" refers to human society. By using the term *naturecultures*, Haraway overcomes this separation and points out that humans are shaped by and are an integral part of the natural world, which is also influenced by human activities and culture. This perspective makes it possible to consider the significant impacts of human activity on the natural world, including pollution, habitat destruction, and climate change. Furthermore, and this seems to be crucial especially for the Engineering Education, a broader perspective on the relationship between humans and the environment can be developed following the epistemological concept *naturecultures*, which goes beyond the idea of nature as a resource to be exploited for the benefit of humans.

Engineers are problem solvers, and that is an important quality. It seems to give them the confidence to see problems as solvable and to approach them with the energy they need. However, as a social scientist, I also see a drawback in reducing the complexity and multi-faceted nature of the world to manageability for engineers. With such an approach, solutions can be found, but these solutions often do not fit the problems posed.

3.2 Understanding Climate Change as a Dealing with "Situatedness"

Feminist epistemology, namely Donna Haraway and Sandra Harding, have drawn attention to the fact that knowledge is always situated (Haraway 1988; Harding 1991). Knowledge, according to this understanding, is shaped and influenced by the specific circumstances and environment in which it is produced or used. The epistemological concept of situated knowledges thus makes it possible to incorporate into the research process the importance of the social, cultural, historical, and political factors that shape knowledge production and use. The advantage of this concept is that it recognizes that knowledge is not created in a vacuum, but is always embedded in powerful structures. Knowledge is also influenced by the unique situations, experiences, and agency of the individuals or communities involved.This perspective, which does not discount the importance of understanding the social and cultural context in which knowledge is created and applied, recognizes that different perspectives and experiences can lead to different forms of knowledge. By understanding that knowledge is situated, students can develop a more realistic understanding the complexity of the world and work toward more inclusive and equitable ways of producing and applying knowledge. This insight, I argue, is central not only to feminist or social science research, but also to more sustainable scientific and technological research.

In my teaching practice, I therefore attach great importance to critically reflecting with the students on the epistemological foundations on which the research is based (Trojer, 2014). In doing so, I want them to understand that developing sustainable solutions is not about developing something particularly technically innovative or sophisticated, but rather about understanding the situatedness of the technical solution as much as possible in order to be able to take this into account when developing possible solutions. In addition to reflecting on the epistemological foundations on which research is based, it is helpful for students to gain insights into more-than-technologically oriented perspectives on climate change problems, or perspectives that address social-cultural aspects in addition to technological ones. Ideally, these are studies critical of power and domination that reveal the intertwining of technological artifacts with the situatedness of individuals and social norms and discourses.

3.3 Critical Reflection – Engineers' tool for Sustainability

When we think of engineers, we usually imagine them designing artifacts on computers, building something, screwing on devices. Perhaps they also program machines or manufacture innovative parts. But what if we added critical reflection as a tool to the engineers' toolbox? I argue that critical reflection on practices of power and domination is central to engineers who want to develop sustainable technologies. My teaching practice made clear, that sustainability has to be understood less as a learning object than as an epistemological perspective. According to that, thinking about sustainability requires the ability to critically reflect on debates, discourses, and paradigms about nature, culture, and technology. This presupposes a discursive understanding of reality, a critical understanding of sociality in terms of power and domination, and a co-constitutive understanding of *naturecultures*. As I have made clear elsewhere (Dornick 2021), learning critical reflexivity is an uncomfortable and difficult process. Moreover, learning critical reflexivity requires engaged learning (hooks 1984). Students must learn to raise questions. This means not only that debates, discourses, and paradigms become in some way foreign to them, but also - especially when it comes to questioning identity categories, such as gender, class, *race* - that students become unsettled. To teach unsettling topics requires a safe and trustworthy learning environment that allows students to activate and practice "free speech, dissent, and pluralistic opinions" (hooks 2010:16), that also considers learning as an embodied process (Thompson 2017). It requires a trusting "interactive relationship between student and teacher and needs a trusting "interactive relationship between student and teacher" (hooks 2010: 19), that motivates intrinsic experimental learning. A good culture of error is essential, as critical reflection leads to uncharted territory. An indispensable factor for this form of learning is time. Students need time to understand and transfer what they have learned to their discipline. As Spelt et al. (2009) point out: “Interdisciplinary thinking does not occur spontaneously, it can take a considerable amount of time for students to achieve an adequate level of expertise in its practice.” It is therefore imperative that the learning process be designed in such a way that students are given time to converse with each other, to communicate in a trusting manner. Only in this way can transfer-knowledge emerge.

4 SUMMARY

The issues of climate change and sustainability are urgent and critical concerns of our time. Engineers play a central role in addressing and adapting to climate change. However, the problem is complex, and the sociocultural consequences of engineering actions are difficult to predict. Therefore, I focused my paper on the content and pedagogical approaches that can be used to convey the complexity of the issue while encouraging the development of critically reflective knowledge. I have argued that it is important for engineers to form a more complex picture of the world. That is, engineers studying sustainability need knowledge of *naturalcultures* in addition to the social and ethical dimensions of technological issues. Besides, students need to knowledge about the epistemological and power-laden foundations of research and the situated nature of the issues. It is important that students gain insight into non-technologically oriented perspectives on climate change issues. Most importantly, it is essential to convey that sustainability is not so much an object of learning as an epistemological perspective and that the ability to critically reflect on technology is therefore critical.

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DISCOVERING SUSTAINABILITY PRACTICES IN RESEARCH AND INNOVATION SITES

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ABSTRACT

This practice paper is a descriptive account of an experience with a sustainable development learning project for engineering students in a Science, Technology and Society (STS) course at Bilkent University. The students participated in the STS Sustainability Awards competition for two semesters in one academic year, an event that was inspired by Bilkent University's 2021–2022 Sustainability Year. As part of the project, the students found a company or laboratory, consulted them on their innovation practices and asked questions that were grounded in Responsible Research and Innovation (RRI) approaches. RRI can provide an opening for students to explore how various values, including sustainability and privacy, are considered in innovation practices. The values by design approach can help engineering students to see that innovators consider both instrumental and qualitative values during the innovation process. Although the project has been used in other years, the sustainability awards motivated students to explore how innovators respond to concerns around a range of sustainability issues. The award recipients produced projects on smart homes, nanotechnology-based solar panels, clean meat, industry 4.0, geothermal energy, air cars and magnetic resonance imaging technology, and gave presentations in events hosted by the Faculty of

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Engineering administrators. Although future research in this area is needed, applied learning experiences, such as the one that is described in this paper, could have the potential to help bridge the disciplinary divide between STS and engineering.

1 INTRODUCTION

1.1 Crossing the Disciplinary Divide

Although engineering students are required to take Science Technology and Society (STS) classes or other classes focused on social, ethical and environmental contexts, they are not always sure why these subjects are part of the curriculum. Engineering students do not always appreciate the practical value of applying social knowledge or ethical approaches. Newberry suggests that students often perceive learning about ethics to be a trivial and useless pursuit, partly because they do not generally see their engineering professors respond to ethical issues (2004, 347). This may be part of the reason that engineering students view societal concerns as “strictly ornamental” (Newberry 2004, 350). Likewise, Cech suggests that although engineering students often start out with a desire to solve societal problems or grand challenges, they typically concentrate on math and science during their first two years of training and this focus may take them away from the societal context culminating in the “culture of disengagement” (2014).

The apparent disconnection between social and technical knowledge among engineering students is an issue that could be addressed through applied projects and the inclusion of social values in engineering classes. It may be helpful for engineering students to receive approval from technical professors for the work that they do on social and environmental projects. Foley and Gibbs suggest that in order for engineering students to take the ethical dimensions of engineering seriously, their efforts in this area must be acknowledged by instructors and institutional administrators (2019, 13). For these reasons, it is important to introduce students to social and ethical issues that come up in the innovation process in a way that allows them to receive recognition for their work on sustainability practices from the engineering faculty in which they are trained. It is also essential to encourage students to engage with innovators, so that they can see how social and environmental values are managed in an applied context.

1.2 Applied STS Projects at Bilkent University

The STS course at Bilkent University is supported by the Faculty of Engineering. It has been managed by the Faculty of Engineering for over twenty years and was originally introduced by Haldun Ozaktas, a Professor in the Department of Electrical and Electronics Engineering (Ozaktas 2013). The main role of the 2-credit course is to respond to Accreditation Board of Engineering and Technology (ABET) goals through addressing social, ethical and environmental values. The course is currently taught by instructors with expertise in Science and Technology Studies and we ask students to engage with innovators for their term projects. Students can use different theoretical approaches, including responsible innovation, social construction of technology and actor network theory. The students typically use interviews to consult the innovators on their innovation practices, but they can also use field notes or website scans.

The STS Sustainability awards competitions were introduced in 2021 and 2022 as part of a larger institutional sustainability initiative (Bilkent University n.d.). The sustainability awards motivated students to explore how innovators respond to concerns around a range of sustainability issues using a responsible research and innovation (RRI) approach. The students identified an innovation site and conducted interviews with engineers at the site. The jury came from several different departments, including urban design, industrial engineering, education and electrical engineering. The jury awarded STS Sustainability Awards to projects that were clearly focused on sustainability, including clean meat, geothermal energy and nanotechnology-based solar panels. They also gave awards to projects that discovered sustainability practices or envisioned future sustainable technologies in the area of smart homes, industry 4.0, air cars and magnetic resonance imaging (MRI) technology. The STS Awards provided an opportunity to showcase STS student work in a formal auditorium setting. The events were hosted by the Faculty of Engineering administrators (Science Technology and Society n.d.). Through conducting RRI studies, the students discovered how a range of values, including sustainability, may be included at an early stage in the innovation process.

2 ENGAGING ENGINEERING STUDENTS IN SOCIAL AND ENVIRONMENTAL ISSUES WITH RESPONSIBLE INNOVATION

2.1 RRI: Beyond Corporate Responsibility

Responsible Research and Innovation (RRI) approaches provide an opening for students to explore how various values are considered in innovation practices. The values by design approach can help engineering students to understand that both instrumental and qualitative values can be included during the innovation process (van de Poel 2015). The social values may include gender inclusion, stakeholder concerns, user experience, privacy and environmental aspects. One of most cited RRI definitions demonstrates that the approach incorporates both economic and social contexts, in addition to tangible outcomes:

> Responsible innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other regarding the ethical acceptability, sustainability and social desirability of the innovation process and its marketable products. (Von Schomberg 2013, 63).

RRI has also caught the attention of industry, which is an indication that it can be useful in an applied context and, for this reason, should be of interest to engineering students (EIRMA n.d.). For example, several Horizon 2020 projects focused on how to assess RRI in industry (van de Poel et al. 2020; Responsible-Industry n.d.). This practical dimension also has applications in engineering education. For example, RRI approaches can be helpful for problem-based learning, partly because it provides a lens for examining responsiveness and solutions (Conley, Tabas and York, 2022; Stilgoe, Owen and McNaughten, 2013).

Sustainable development and responsible innovation intersect in many ways and provide methods and opportunities for both engineering educators and industrial actors to include social and environmental values. As a concept, sustainability has been embraced by industry and environmentalists, even though these stakeholders often have different understandings of the term (Robinson, 2004). However, these differences provide flexible opportunities for the inclusion of various values. The Brundtland report called for sustainability assessment tools to be further developed at an early stage, but they remain notoriously difficult to implement: "[T]he tools for monitoring and evaluating sustainable development are rudimentary and require further refinement" (Brundtland 1987, 256). Indeed, corporate strategies have not always developed in complete alignment with the Brundtland report (Barkemeyer et. al. 2014. 28). Although innovators have had corporate social responsibility (CSR) strategies in their company objectives for some time, it is difficult to standardize measurements (van Marrewijk, 2003; Contrafatto and Burns, 2013, 359). Much like sustainability, responsible innovation is a flexible concept that includes a focus on economic aspects, innovation and social and environmental issues (Guston, 2015). Given that views and definitions for sustainable development and responsible innovations can vary, it may be helpful to use qualitative approaches as assessment tools, mainly because they offer more versatility and can also be used to promote better practices.

Some scholars have been investigating the relevance of RRI for industry, which is clearly significant for future engineers. Developments in RRI that use qualitative assessments may be more appropriate for discovering concrete results and sustainability practices. For example, PRISMA is an RRI project that investigates company practices. The project used a bottom up approach to RRI investigations and recognizes that companies are already engaging in some responsible practices. For example, some companies have CSR practices in place and they also pay attention to conflicts between values. The PRISMA researchers have found, for example, that profit sometimes supersedes stakeholder interests and transparency (van de Poel et al. 2020, 699). They also suggest that companies can improve RRI practices through the following methods: "strategize for stakeholder engagement", "broaden current assessments", "place values at center stage", "experiment for responsiveness", "monitor RRI progress" and "aim for shared value" (van de Poel et al. 2020). The responsiveness element goes beyond merely discovering values to realizing outcomes. In this way, RRI goes beyond CSR assessments. By suggesting that companies experiment for responsiveness, they also draw attention to the technical creativity that is needed to discover potential solutions to social and environmental risks. This is also a key part of the exercise for the STS students.

2.2 Applied RRI for Engineering Students

The applied projects have created a new opportunity for educating STS engineers in responsible innovation theories and methods. In a group context, students identify a company or a lab and conduct research through interviews or ethnographic approaches. Students are asked to engage in an investigation of one field site (a lab or a company), reflect on a range of values in the innovation process and consider some of the trade-offs that are made by engineers and scientists in a real-world setting. Students examine the role of users and stakeholders, investigate relevant policy developments, identify potential risk issues and, if relevant, discover responsible solutions. The groups choose a variety of sites, including, for example, social media companies, energy companies, simulation research centres, medical imaging projects, nanotechnology labs, cyber security companies, factories, alternative meat production and artificial intelligence applications.

Through the analysis, the students uncover various aspects of RRI that are important to their sites of analysis. These include collaborations with different stakeholders or academics from different disciplines, the inclusion of user experience in innovation, attention to privacy by design practices and the identification of possible solutions to social concerns. Students are able to assess key risks and benefits, which may generally arise in the specific research and innovation context where they are conducting their interviews. The initial desk research that students conduct enables the students to ask representatives from labs and companies pertinent questions about their innovation practices. Students often find that researchers have considered social and ethical values during the innovation process. In some cases, their research findings demonstrate that innovators respond to these risks with technical adjustments or they make changes to the practices or policies associated with the technical development. This can be surprising for some students, as this part of the innovation process is not typically highlighted in their engineering classes. If students find examples of technological adjustments that respond directly to social or environmental concerns, such as privacy-respecting mechanisms or sustainability measures, in their background research, then they are in a position to make suggestions for how the company or lab can address risk issues in the analysis section of their term project.

3 STS SUSTAINABILITY AWARDS

3.1 Method and General Outcomes

As a part of the 2021 and 2022 sustainability awards competitions, students were asked to use a responsible innovation approach and place an emphasis on sustainability. The students recruited companies and research sites, conducted their interviews, analyzed their interview transcripts and finalized their reports. The students reported on all of the values that they found through their research and highlighted values related to sustainability. Some students found that engineers considered sustainability solutions. Students also learned that innovators encountered value conflicts in their attempts to find sustainable solutions. The Faculty of Engineering administration supported the event through making and giving out certificates and listening to student presentations. Their participation helped to give the event prestige, which may have also helped to motivate the engineering students.

At the end of the Fall 2021 and Winter 2022 terms, the jury reviewed projects and considered them for the STS Sustainability awards. In the Fall semester, ten projects were sent to the jury from twelve STS sections (about 240 students) and they gave awards to five projects. In the Winter semester, the jury awarded three projects from six sections (about 120 students). The jury assessed the projects according to a focus on sustainability (40 marks), attention to key stakeholders (10 marks), the inclusion of relevant risk issues (10 marks), attention to solutions to risk issues and stakeholder concerns (10 marks), originality and creativity (20 marks) and writing (10 marks). The award categories varied in each semester, but included Outstanding STS Sustainability Award, Sustainability and Innovation Award, Social Justice and

Sustainability Award, Energy Futures and Sustainability Award and the Sustainability and Equity Award. Seven of the projects that received awards agreed to post their projects on the STS website after receiving permission from the companies that participated in their studies. I will provide some general examples of findings from their reports related to sustainability below (Science Technology and Society n.d).

Table 1. Sustainability Findings in Student Projects

Types of sustainability findings in student projects	Projects
Projects focused on sustainability technologies	• Cultured Meat: Meet the New Meat (Outstanding STS Sustainability Award 2021) • Sustainability Analysis of Turkey's Leading Geothermal Energy Company Based on Responsible Research and Innovation Theory (Energy Futures and Sustainability Award 2021**)** • Graphene-Based Solar Cells in the context of Responsible Research and Innovation (Outstanding STS Sustainability Award 2022)
Projects that found value conflicts related to sustainability	• Graphene-Based Solar Cells in the context of Responsible Research and Innovation (Outstanding STS Sustainability Award 2022)
Projects that discovered examples of the inclusion of sustainability adjustments to the technology	• Graphene-Based Solar Cells in the context of Responsible Research and Innovation (Outstanding STS Sustainability Award 2022) • Tangible Social Concerns in a Digitalized World: An RRI Case Study on Digital Transformation Technologies at TEKNOPAR **(**Sustainability and Equity Award 2022) • A Case Study on Karel Electronics Smart Home Technology Through the Lens of Responsible Innovation (Social Justice and Sustainability Award 2021)
Projects that identified sustainable practices	• AirCar: A "Jetsons" Dream Coming True (Sustainability and Innovation Award 2022)
Projects that included a vision for a future sustainable technology	• AirCar: A "Jetsons" Dream Coming True (Sustainability and Innovation Award 2022**)** • Responsible MRI: RMRI (Sustainability and Innovation Award 2021)

There were a few examples of companies that were working towards sustainable development goals, but award recipients also found examples of sustainability practices in other sectors (see Table 1; Science Technology and Society n.d.). For example, the geothermal project and the clean meat projects found that sustainability was a key goal for the companies that they consulted, so they were clearly building environmental values into their technology. The geothermal project noted that the company wanted to be the energy company of the future for Turkey and envisioned a future that would us mainly renewable sources. Students found that Biftek emphasized how conventional meat is not a sustainable option and a transition to clean meat would help to solve this problem. While Graphene-Based Solar Cells is obviously focused on developing sustainable technology, students also discovered that researcher and engineers sometimes encountered conflicts between different types of values. For instance, through their interviews, students found that it is economically more viable to work with heavy metals, but they chose to use boron instead as it is a more sustainable option. The students pointed out that the innovators made this decision because they were concerned about environmental values. Other groups found that their interviews had made technical adjustments to improve sustainability. For example, TEKNOPAR used sensors that would keep track of electricity use and potentially reduce greenhouse gas emissions. Similarly, Karel had implemented smart plugs and lighting for the same purpose. The interviewees from the AirCar company indicated to students that their future technology would not actually be owned by individuals. Rather, they envisioned that future air cars would be shared by users, which is similar to sustainable car sharing practices that are already in place. Students also found that some of the sustainable technologies that were discussed by the innovators are still at the aspirational stage. However, although the AirCar technology is still in development, the engineers were already working towards significantly reducing emissions. Finally, the MRI group noted that the future development of smaller MRIs would make the technology more sustainable.

4 SUMMARY AND ACKNOWLEDGMENTS

4.1 Summary

The STS Sustainability Awards were an opportunity for engineering students to learn about sustainability issues, examine the unintended risks and identify possible solutions by using responsible research and innovation approaches. The students discovered industry-based sustainability practices through their efforts. It is possible that students may have a better understanding of the relevance of social and environmental values through conducting their investigations, but this would need further research. As noted above, engineering students do not always view courses that focus on social knowledge as relevant to their future technical careers. This learning activity addressed this problem in two ways. Firstly, by consulting innovators on the values that are included in the innovation process, students had an opportunity to realize that social values, including sustainability, are routinely considered by researchers and real-world developers. Secondly, perhaps by including participation from engineering faculty in STS course activities, it may have helped to validate the time that engineering students spent on the responsible innovation inquiries. However, these issues would need to be explored further by future researchers, as this paper only describes the project, the competitions and some of the key findings from student projects. Of course, there are ways that the project can be improved, if implemented again in the future. Although it is useful for students to find a company that is actively working on sustainable technologies, it is also important to discover the conflicts, risks or unanticipated consequences associated with the sustainable innovation that they are examining. This aspect does not always receive as much attention. Also, it is important to stay open to sustainable innovation practices in all sectors, rather than only investigating innovations that are exclusively focused on sustainability. Students were asked to imagine solutions for sustainability dilemmas, particularly if the innovators that they interviewed did not mention one, but this was not always successfully addressed. This dimension could be developed much further, although students may not have always have time to identify appropriate solutions. Overall, the sustainability competition was a successful initiative, as it helped students to reflect on sustainability in innovation practices. The STS Sustainability Awards also provided a useful way to draw attention to STS student work on sustainability, as representatives from the Faculty of Engineering attended the events, presented certificates to award winners and heard the students give talks on their projects.

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Does Interdisciplinary Creative Coding Boost Creativity? A Mixed Methods Approach

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ABSTRACT

This study explores the influence of an interdisciplinary intervention on creative problem-solving skills. Literature deems such skills as vital for software engineering (SE) students in higher education. 39 SE students and graphic design (GD) students were randomly paired to work on an open-ended creative coding assignment in p5.js, an online JS-based Processing editor that makes it easy for novices to quickly and easily code visual webpages. Three categories were formed: the test group SE+GD (18 students), and control groups SE+SE (10) and GD+GD (11).

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A mixed methods approach was taken to gather and interpret results: Amabile's Consensual Assessment Technique provided a global creativity score for the finished product, the Creative Programming Problem Solving Test assessed three dimensions of the creative process (*Ability, Mindset, Interaction)*, and 9 semi-structured follow-up interviews provided context and revealed underlying themes. The results indicate that, while the creativity of the end product initially takes a hit, the SE+GD groups' socio-interactive creativity levels increased. We also observed fixed mindsets towards creativity ("design students are more creative than we") that call for future work.

1 INTRODUCTION

Many studies emphasize creativity as an essential problem-solving skill in the world of computing (Apiola and Sutinen 2020; Salgian et al. 2013). A recent Delphi study reveals: SE industry experts rate creativity as crucial to succeed as a developer (Groeneveld et al. 2020). Another study concluded that in order to foster creativity in higher education, three approaches can be taken (Groeneveld, Becker, and Vennekens 2021):

- Introduce experimental learning. Experiments with open-ended project-based learning have been shown to be beneficial towards students' creativity.
- Get students out of the classroom. The environment in which the learning takes place plays a significant part in the creative potential of students.
- Put creativity first, programming second. This opens up computing to a more diverse student population.

This paper provides an experience report that combines all three approaches and adds upon it by introducing an interdisciplinary approach for developing SE student's creative skills. In our approach SE students are paired with GD students in an experimental open-ended learning project using creative coding in the programming framework p5.js. The project took place in the design classrooms of another university. And lastly, we put creativity first by refraining from grading and emphasizing on experimentation and having fun as a goal in itself.

The goal was to amplify creative problem-solving capabilities of SE students in higher education, beyond the conventional approaches. Since creativity can express itself in different ways, we ask the following questions:

- **RQ1**: *What is the influence of an interdisciplinary creative coding project on the creativity of the* ***process****?*
- **RQ2**: *What is the influence of an interdisciplinary creative coding project on the creativity of the* ***end product****?*

The remainder of this paper is structured as follows. Section 2 outlines related work, Section 3 describes the mixed methods approach utilized to gather results. Those results are presented and discussed at length in Section 4. Next, in Section 5, we highlight possible limitations of this work. Finally, Section 6 concludes this research and suggests future work.

2 BACKGROUND

2.1 Interdisciplinary collaboration

In the paper “Ten Cheers for Interdisciplinarity” (Nissani 1997) creativity is considered one of the reasons to pursue interdisciplinary collaborations. "Interdisciplinary computing classes are worth the effort", concludes Lori Carter (Carter 2014). We believe this to be especially relevant in the field of computing where the demand for interdisciplinary skill crossovers is growing, according to (Carr, Jones, and Wei 2020).

2.2 Creative coding

The concept "creative coding" is often employed in curricula to explore code as a medium for self-expression (Peppler and Kafai 2009). The focus here is not sparking creativity to deal with daily programming problems, but rather to use code to express your creative urge. This is typically done using the Processing (p5.js) programming language and has been known to increase engagement and excitement for computing (Greenberg, Xu, and Kumar 2013). The focus on visual creations entices students, while at the same time offering a decent programming challenge.

2.3 Creativity and how to assess it

Creativity is a broad concept that, even when viewed from a computational perspective, seems to codify multiple perspectives: creativity by yourself, in teams, or on socio-organizational levels (Veale, Gervás, and Pease 2006). Precisely because of ongoing discussions whether or not the concept of creativity is context-dependent (Baer 2010) and disagreements on numerous definitions of creativity (Groeneveld, Becker, and Vennekens 2021), a plethora of assessment techniques have been published. Yet many existing assessment tools, including those from the field of cognitive psychology, fall short of measuring multiple dimensions of creativity. For instance, the well-known Torrance Test of Creative Thinking (Torrance 1972) gauges divergent thinking but ignores creative collaborative aspects. Personality-based self-tests such as The Big Five emphasize individual creativity and motivation (Sung and Choi 2009). Amabile's Consensual Assessment Technique (CAT) employs a jury to score the creative output but ignores the creative process (Amabile 1982). Recently, a new creativity self-assessment tool was developed specifically geared towards problem solving for computing students, called the Creative Programming Problem Solving Test (CPPST) (Groeneveld et al. 2022). It contains three overarching constructs of creativity based on existing validated scales and conducted focus groups: *Ability* (knowledge of coding and creative techniques), *Mindset* (curiosity and belief in own abilities), and *Interaction* (social aspects of creativity).

3 METHODOLOGY

Before elaborating on the data gathering processes, to help the reader interpret the results, we first describe the target groups involved in this study.

3.1 The Setting

Students from two entirely different programs took part in the experiment: 19 second-year students from our local faculty of engineering technology electronics/ICT and informatics (SE) and 20 students from the faculty of visual design from a neighboring university (GD). As creative skills are a learning outcome for both groups of students, all students were expected to participate, but to avoid pressure no grades were attached to the process nor to the results. Students could also bail out of filling out any form or participating in the interviews without any consequences, resulting in a setup following the guidelines of the Privacy and Ethics Unit of the university.

All participants were randomly placed into one of three groups: The test group SE+GD (18 students, 9 duos), the control group SE+SE (10 students, 5 duos) or the control group GD+GD (11 students, 4 duos and 1 trio). None of the students had prior experience with the p5.js framework. So an introduction session of two hours was given to all participants. In this study, the decision to use Processing was not made to explore creativity as a means for self-expression like in (Peppler and Kafai 2009), but as a means for problem solving. To minimize unwanted side effects during measurements, all groups were placed in the same physical location, including control groups SE+SE and GD+GD. We chose the buildings of the design faculty for the location since we were most interested in the possible deltas of SE students and, as explained before, wanted to "get students out of the classroom". Of course, for the design students, the location didn't change. As for the project assignment itself, it was delineated, but not too much, as to leave room for creative freedom. The pairs had to create a visual exposition that emphasizes user interaction, for instance through sound, camera, or mouse input. The assignment had to be completed on a single day. All projects were incorporated into an online p5.js exposition.

3.2 Measuring The End Result: CAT

Well beyond the field of cognitive psychology, Amabile's CAT is commonly used to evaluate the creativity of an end product (Baer and McKool 2009), in our case, each p5.js project. CAT relies on expert judges that score the creativity of an end product between 1 and 10. Since the scoring process is very subjective, it is recommended to recruit multiple judges and work with an average. For this study, we enlisted seven judges that are part of the teaching staff of the involved courses: three computing experts (all co-authors), and four GD experts, of which two eventually opted out of the study. The judges were instructed in individually evaluating the creativity of each anonymized project by spending exactly one minute on each project. We refrained from providing a definition of creativity, as per recommendation in (Baer and McKool 2009). The standard deviation (SD) of the scores, on average 1.44, mirrored Baer and McKool's conclusion: judges score surprisingly similar (Baer and McKool 2009).Therefore, for CAT, inter-rater reliabilities are not relevant. However, as an extra verification step, when judges did not agree (threshold of $SD > 1.80$, 5 out of 19 or 26% of the projects), those projects were re-discussed in group, after which new scores were assigned and an SD calculated, until the threshold was reached.

3.3 Measuring The End Result: CPPST

Next to evaluating the end result with CAT, we were also interested in different aspects of the creative process. The CPPST tool allows us to assess whether or not our interdisciplinary intervention has effect on specific parts of students' creative problem solving abilities. The CPPST is a self-assessment test which was administered at the end of the project day. In it, students answer 56 questions on a Likert-5 scale. The full question set is available in (Groeneveld et al. 2022). A reduced set of 32 questions are enough to gauge the three factors of the CPPST, but we opted to include the full set as the extra data might help us in asking more specific questions in the semi-structured interviews.

3.4 Enriching quantitative data: interviews

The different CAT and CPPST values are devoid of rich contextual information. Therefore, we decided to conduct additional interviews to put these numbers into context based on the results of the aforementioned tests. After the CPPST survey results were collected, average and SD values were calculated for each question, grouped by the three student categories. Next, since we were most interested in the impact of the interdisciplinary component, deltas (δ) of averages between the subgroup SE from SE+GD vs SE+SE and the subgroup GD from SE+GD vs GD+GD were calculated. A $\delta > 0.5$ was marked as potentially interesting. Hove and Anda's recommendations for conducting semi-structured interviews in empirical SE research (Hove and Anda 2005) combined with a discussion of the deviating δ values of the CPPST results guided us to the following question sets, divided into two distinct themes: **general context** (1-2) and more **in-depth**-related (3-9) questions:

1) What did you think of the experience?
2) How did the collaboration go?
3) How did you tackle the project in general?
4) How did you tackle brainstorming and ideation?
5) What did you do when a problem occurred and you were stuck?
6) What did you learn with this project?
7) In which way did you get out of your comfort zone?
8) How did you tackle the openness of the assignment?
9) What would you do different if you were to re-do it?

Our aim was to interview a random selection of 30% of the participants of each group. Data from the interviews was processed using qualitative coding as presented by Onwuegbuzie et al. (Onwuegbuzie et al. 2009). The transcripts were read multiple times independently by two co-authors to apply an open coding step, initially identifying 43 codes. Next, in order to identify patterns, notes were compared, cross-validated, and reduced into 25 codes grouped into 4 themes in an axial coding step. These themes served as a starting point for discussion and to cross-link back to the quantitative results. The resulting themes and codes are presented in section 4.

4 RESULTS AND DISCUSSION

At the end of the project day, all pairs successfully created an interactive visual exposition. An overview of the projects, together with all open data used in this study, is available at https://arneduyver.github.io/creative-coding/gallery. Some examples:

- Abstract art that reacts to sound or mouse input.
- "Draw in the air" using the camera.
- A text to music generator.

4.1 Quantitative results

The CAT scores of the SE+GD, SE+SE and GD+GD groups were respectively 6.30, 6.88 and 6.04. Although these differences can be considered small, it is interesting to note that the test group of interdisciplinary teams (SE+GD) scored with 6.30 less than the pure SE teams (6.88). To verify if the differences originate from the creative process, we took a closer look at the CPPST measurements (on a scale of 5).

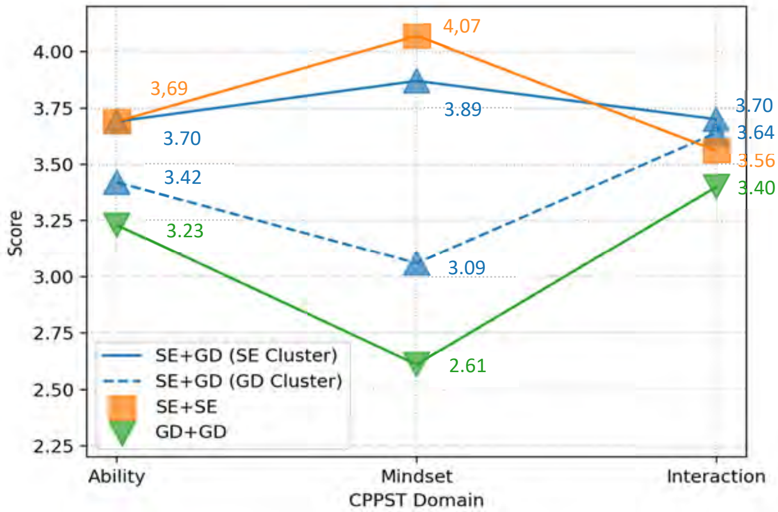

Figure 1: Average CPPST domains for groups SE+GD (△), SE+SE (□), GD+GD (▽).

Figure 1 shows that the interdisciplinary test group performed marginally better at *Interaction* level, and especially in the socio-interactive components of creativity, probably because their different backgrounds enforce more discussion. However, the biggest gap is in *Mindset* with low scores for for the GD+GD group, but also for the SE+GD groups with a GD majority. It might be that they struggled with the complexity of programming and had no access to a SE student to solve this, or it might be a sign of a fixed mindset (“I can’t code”) that resulted in an early defeat. As CAT and CPPST are devoid of context, a qualitative interpretation is needed.

4.2 Qualitative results

In total, 9 students were interviewed: 5 from the SE+GD group (3 from SE and 2 from GD, thus 29.4% of that population), 3 from the SE+SE group (33.3%), and 1 from the GD+GD group (9%). Since we are mostly interested in the effects of the intervention on the SE students, we do not consider the small GD sample size as a threat to the validity of the study. Transcript analysis initially yielded 43 codes across all groups, reduced to 25 and categorized in 4 distinct themes: *Curiosity* (6), *Cooperation* (7), *Method* (7), and *Mindset* (5). We now briefly describe findings of each of the themes with codes emphasized in bold.

CURIOSITY - Almost all interviewees appreciated the opportunity given to **explore beyond their education**. SE students mentioned they "*had no idea it was that easy to create something visually*". Especially **being in the same space** turned out to be inspirational, as students regularly got up to see others at work and mentioned ideas cross-pollinated quicker that way. The unique **physical environment**, as per recommendation in (Groeneveld, Becker, and Vennekens 2021), seemed to inspire SE students:

> *I was very impressed because as you entered, there were drawing tablets, 3D printers, a green room for photography, ...Then more ideas will come to you.*

Another trigger for curiosity was p5.js itself, as the **framework facilitated play**: students praised the clarity of the documentation and the easy-to-use web editor that facilitates experimentation through rapid feedback. The **freedom** and absence of the stress in anticipation of a grade was also reported to play a role. The interviews also revealed that **frustration** was a big factor limiting creativity.

COOPERATION - SE+SE students working in a homogeneous group mentioned cooperation was **smooth**, even if they did not know their partner. Yet, for the heterogeneous SE+GD group, collaborating was **very difficult**. "*Working together with a complete stranger was hard.*" When asked why, several reasons were given: (1) It was "*difficult to explain your own way of thinking*"; (2) "*I really had to drag it all out [of my partner]*". (3) Some students wanted to get to know their partner, while others wanted to start coding immediately. The different fields of study might also imply a difference in personality and approach. **Giving feedback** proved to be a challenge as well. The interviews confirm that the social aspects of co-creating was what pushed students **out of their comfort zone**. Some homogeneous interviewees realized that cooperating--and possibly, the creative outcome--would be **very different in a mixed group**, but in a good way: "*I found projects from the mixed group to be excelling [...] they had ideas that were more interesting than ours*". Although "*more interesting*" did not result in higher average CAT scores, all students do **acknowledge that cooperation is an important factor** to creative success.

METHOD - SE+SE and GD+GD groups applied **different approaches**. The former look at examples, think about what they like to do based on the examples, and immediately start exploring that in code, while the latter first brainstorm for ideas, sometimes **iterating** over them, and only then look at what is possible to try and implement their ideas. SE students mentioned they had **difficulties with the openness of the assignment**. Some SE+SE students admitted spending too much time trying to come up with a concept, struggling with what they wanted to create. For SE+GD groups, there was a **stereotypical task division**: "you *do the code, I'll do the design*". As to what to do when stuck, SE+GD students mentioned they liked to "***get up and walk around*** *[...] I take that as a moment to think about something else [...] and usually come back with a solution*". SE+SE students prefer **diving into the docs** before asking for help.

MINDSET - Interviews revealed many **prejudices**: from "*creating something visual is hard*" (SE) to "*I can't code*" (GD). As much as everyone acknowledged **importance of heterogeneity in teams** and lauded the experiment as **refreshing**, we discovered a **fixed mindset** when it comes to creativity. SE students say "*design students go more in the creative direction while we use logical steps to solve things*", while GD students say "*coding is very mathematical*" and imply it is less creative than their visual work. Clearly, this fixed mindset can be very damaging to the creative potential of SE students. Also, students have a **wrong image** of what an engineer or designer does, as a GD student testified:

> *I think we're more the people who ask questions while you just tell an engineer to do this or that and he'll understand it that way.*

5 LIMITATIONS

This paper reports on an intervention with a relatively small group ($n = 39$). Although judging from the recurring themes throughout the interviews, we believe that the findings of this paper will persist. Since the cooperation between different student groups caused friction, a prolonged intervention of for instance a week could iron out the initial acquaintance difficulties. We suspect that the CPPST *Interaction* δ between the groups would even be bigger then, possibly also increasing *Ability*, but the creativity prejudices would likely remain. Future work might shed more light on this.

6 CONCLUSION

This study explored the influence of an interdisciplinary intervention on creative problem-solving skills by pairing up SE students with GD students. A mixed methods approach helped in identifying and understanding the various effects of the intervention. While we observed a slight decrease in the creativity of the end product (RQ1), the CPPST reveals that although *Mindset* needs more work, our intervention effectively increased the *Interaction* part of the creative problem-solving process (RQ2). It is important to note that due to the various reasons touched upon while discussing the qualitative results in Section 4.2, creativity can initially take a hit during interventions. This should not worry educators but is something to be aware of. Using a measurement such as CAT is not enough to reveal the underlying constructs behind the numbers. As many students testified, the intervention was a great experience to get a taste of *real* creative cooperation, even though this is not visible by looking at the CAT results. And yet, a recent literature review revealed that most computing education studies on creativity employ a single metric (Groeneveld, Becker, and Vennekens 2021). We also found the fixed mindset approach towards creativity to be very problematic, especially for the teaching staff who try to improve the creative skills of students. This has also been noted by Apiola & Sutinen (Apiola and Sutinen 2020) and Groeneveld et al. (Groeneveld et al. 2022). We have not encountered any studies that try to mitigate this. We see no easy solution and thus feel that this requires immediate attention from the computing education community.

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PROBLEM-SOLVING SKILLS DECONSTRUCED AND IMPLEMENTED IN AN ADAPTIVE LEARNING TOOL

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ABSTRACT

The development of problem-solving skills is an important subject in engineering curricula. Helping novice students develop such skills can be challenging because problem solving is a complex skill in the sense that it is accompanied with an internal thinking process that many experts are even unaware of doing. From a combination of literature and a thinking-aloud exercise with the entire teaching team, a scheme with building blocks and strategies that are commonly used by engineers was constructed. In addition to commonly named steps such as Identify/Define, Plan/Choose, Carry Out/Do and Look back/Inspect the scheme refines the first step into multiple interdependent building blocks, emphasizes the need for critical reflection at each point as well as the possible need to return to previous steps at any time. Moreover, multiple correct solution paths can be followed in solving a problem. To address this and to empower the students in their divergent thinking processes when solving a problem, an innovative intra-exercise adaptive e-learning tool was created. The anywhere-anytime availability enables for virtual and remote learning in the post-COVID world. In the learning tool students can choose between different solution paths, after firstly identifying the correct context, parameters etc. This paper describes the process of defining the building blocks, resulting strategy scheme and implementation of the building blocks in the adaptive e-learning tool. Initial findings indicate that the strategy scheme consisting of building blocks and the adaptive e-learning tool help students in developing their problem-solving skills.

1 INTRODUCTION

As stated by Docktor et al., solving complex problems is an essential skill for all to possess (Docktor et al. 2016). This is especially true for engineers since problem solving plays an important role in their profession. Many higher education institutions therefore see it as an important task to help engineering students develop their problem-solving skills (Neri et al. 2010; Pavlasek 2014). However, Harshkamp and Suhre noticed that students are often taught to solve problems by using solution methods for a specific topic, e.g. in engineering mathematics or physics courses, and less time is devoted to teaching general problem-solving skills (Harskamp and Suhre 2007). The risk of this is that students see problem solving as performing a predefined number of steps dependent on the actual topic. Yet students are expected to solve ill-structured problems in a variety of domains once graduated (McNeill et al. 2016). Our contribution is that we have deconstructed problem-solving skills in more detail than previous work, and conveyed it to first year engineering students in a specific course on problem-solving skills. As problem solving is not a linear process and as multiple paths can lead to a solution, we have also implemented a number of online learning modules with intra-exercise adaptivity and multi-branched solution trees that support the divergent thinking of different types of students. This contrasts with existing tools that guide the student in a fixed, predefined path.

We begin this paper with a *Rationale,* based on a *Literature Overview. "A problem"* is defined and an overview is given of methods for teaching and measuring problem-solving skills, including digital and adaptive learning tools. Next, *Developing the problem-solving building blocks*, describes the process of deconstruction and the resulting problem-solving scheme consisting of building blocks and strategies commonly used by problem solvers. In *Applying the building blocks in teaching,* we show our implementation in- and outside class. *Reported Effects* discusses the findings of a questionnaire answered by 101 out of 194 students. Points of attention and continued research are the subject of *Threats to validity and Future Work. Conclusion* summarizes the main findings.

2 RATIONALE

To be able to teach problem-solving skills, we need a definition of "a problem" and "problem-solving skills". We start with the general definition of a problem (Maloney, 2011):

> *"Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap, you have a problem."*

This broad definition aligns well with our own idea of a problem since it makes an implicit, but important distinction between performing a task and solving a complex problem. For us, anything that can be solved by following a straightforward procedure is to be considered a task, not a problem, i.e., it is only a problem if *'<u>you</u> don't know how to <u>find a way</u>'.* A problem solver is somebody who finds such a way. In the quote we intentionally underlined not only *<u>find a way</u>*, but also *<u>you</u>*: a task for an expert can be a very big problem for a novice: because of unfamiliarity with the subject, but also because of inexperience with problem solving. Experts are not only an expert in the domain (the *what*), but are also experts in organizing their knowledge (the *how*) in order to see the core relevant principles applicable to the problem at hand, whereas the decision-making process of novices is more narrowly context related (Docktor et al. 2016; Neri et al. 2010).
The strong link with context is prominently present in most approaches to teaching problem solving skills, tying it to a concrete subject (Docktor et al. 2016; Neri et al. 2010; Harskamp and Suhre 2007). However, others put the generic skills first (Kalyuga and Sweller 2005) and stress the uncertainty in the path to the goal and the fact that making mistakes and problem solving go hand in hand (Martinez 1998). We adhere to this vision and have deconstructed problem-solving skills into a set of thought constructs that may help in paving a path, independent of the actual problem domain. We also take care of making students comfortable with the idea that reflecting often and even backtracking, is not a failure, but a very typical instrument of the expert problem solver.
Proper support is needed for the students in this potentially uncomfortable endeavor, both inside and outside class. E-learning has been used before for problem solving, e.g. in the domain of physics (Neri et al. 2010), mathematics (Harskamp and Suhre 2007; Melis et al., 2001), or STEM (Netwong 2018), and even the concept has been mentioned, e.g. "intra-exercise adaptivity" (Göller et al. 2017). "intra-exercise branching" (Mei and Heitzer 2017) and "a branching system of programmed instruction" (Lockee, Moore, and Burton 2004), but we have not found examples of explicit support for multiple solutions paths in generic problem solving with continued feedback along each path.

3 DECONSTRUCTING PROBLEM-SOLVING INTO BUILDING BLOCKS

3.1 Context

In 2018 a specific course on problem solving skills, Basic Engineering Skills (BES), was introduced in our faculty of Engineering Technology at [university omitted for anonymity]. The course is part of the general engineering phase of three semesters, after which students choose one of seven options such as Chemistry, Construction Engineering, Electromechanics, Software Systems, … and is also part of the bridging program for students who already graduated in a related bachelor's degree, e.g. in chemistry or electronics, and seek to acquire a master in engineering technology.
Focusing on problem solving and not on the underlying subject, the problem domains of the exercises were carefully selected to match the knowledge and skill set of the incoming students, who could also use a reference sheet of basic, frequently used formulas. This ought to create a common ground and align with the practice of many courses where problem-solving exercises are used to assess students' comprehension on a certain topic (Docktor et al. 2016; Neri et al. 2010). As the difficulty of the context is reduced in our approach, we hoped to be working only on the problem-solving skills. However, depending on both the background and envisioned major of the students, the perception of the exercises ranged from a (complex) task to a real problem. E.g. an exercise with a context from chemistry, would be a task for a student with a strong chemical background, at the same time posing a challenging problem for a student orientated at computer science. To overcome this, we started an educational innovation project in 2022.

3.2 The process

Because we see problem solving as a complex skill accompanied with an internal thinking process that many experts are even unaware of doing, we deemed it important to first make the unconscious problem-solving schemes and strategies explicit. The first step therefore consisted of a thinking-aloud exercise similar to a method to gauge the level of problem-solving skills of students by having them verbally explain every step in solving the problem as is described in literature (Docktor et al. 2016; Mueller et al. 2017). Each member of the BES teaching team (seven experienced lecturers from five different disciplines) was instructed to individually note every little step of their problem-solving process while solving the same problem as the other participants. Next, pairs were formed in which the approaches were discussed in depth. Finally, a group discussion took place which revealed many different paths, but also similar strategies for approaching the problem. This resulted in the identification of a set of core principles, which were refined into a set of building blocks and the interactions between them.

3.3 The building blocks

In our vision problem-solving can be deconstructed into the following elementary building blocks: Read, Analyze, Structure, Select context and formulas, Generate potential solution paths, Solve and Evaluate, and Report final result. Critical Reflection is an overarching block. Our blocks expand upon the four very basic blocks: (1) understand, (2) choose/make a plan, (3) do/carry out the plan, and (4) inspect/look back (Maloney, 2011), (Polya 2004).

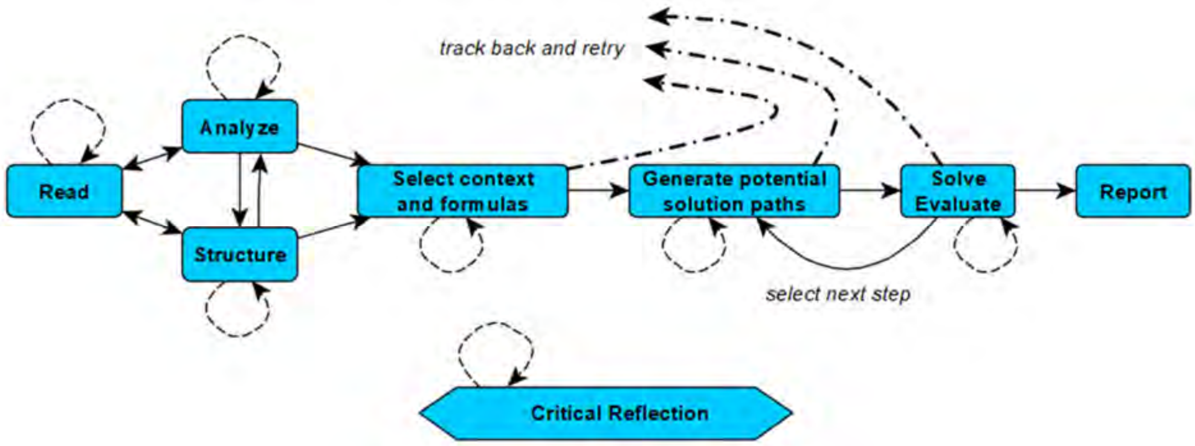

Figure 1: Problem-solving building blocks and their internal control flow.

The central idea is that the blocks do not form a step-by-step plan, but rather a toolbox that can be applied in any suitable order and that can result in a wide tree of approaches to solve the problem at hand. Therefore, the order implied by the solid arrows in Figure 1 is merely a suggestion–unless performing a task. However, when a problem must be solved, there is no direct path from reading the problem description to solving it and reporting the solution. Instead, one needs to figure out possible paths and backtrack when a previous decision turned out to be ineffective. This is denoted by the dash-dot lines.
Equally important are the dashed circles, implying critical reflection and repetition. Critical reflection entails a continuous questioning of the work done: did I read properly, is my sketch complete, is the (partial) solution meaningful, … Also, each building block is probably to be applied several times, e.g. in *Read* one can first scan the assignment to understand the major context and then return to reading when the precise input values are needed; for *Structure* a basis sketch could be made at first, and later on more details can be added. Especially after backtracking, a building block should be reconsidered, e.g. read the assignment again to verify assumptions, select a different context, generate and/or select a different solution path, …
Also notice that after solving a path, the problem solver should evaluate the outcome. When it contains the solution, report it in a proper format. If it is a step in the right direction, select the next step by generating a new path. Otherwise, track back.

3.4 The reported solution does not represent the problem-solving process.

An eye opener to us was the sudden understanding that handing out model solutions for the various exercises did not help students in becoming better problem solvers. The first obvious reason is the absence of different solutions paths, unless many model solutions would be prepared, but more important is the fact that in a model solution the different steps are presented linearly, whereas problem solving is always a back-and-forth process trying out different solutions paths. This simply cannot be made visible in a model solution. We still stress the importance of writing down the final solution in a structured manner, but explicitly position it as a distinct and final phase.

4 APPLYING THE BUILDING BLOCKS IN TEACHING

Although we hinted earlier that uniformly paced on-campus lectures are not perfect, they still are important for introducing the concept and for elucidating it by giving a few examples of different paths that are derived from the same set of building blocks and that lead to the same solution. Next, students solve some problems in class with guidance by the lecturer who always refers to the building blocks as they are applied. We consider the explicit reflection on the concrete stage in the problem-solving process by referring to the building blocks an innovative approach on teaching problem solving skills.

To support the students outside of the classroom, online learning modules were developed for a variety of exercises and contexts. The idea is that students first try to solve the problem without the online module. When the student provides the correct answer, a model solution is presented as an example of how to properly structure a solution. In the case of a wrong answer, feedback is shown and options are given. Just as in the on-campus lectures, we explicitly mention the building block they are currently handling to make the thought process explicit. We thus target a consistent learning experience in respect to the building blocks regardless of the learning lieu (online or on-campus), while at the same time taking care that on-campus and online complement each other. As the covid-era learnt that online teaching simply cannot serve as a full substitute for the social experience of co-learning with fellow students, with our approach we combine the social benefits of on-campus teaching with the benefits of independence and self-pacedness of online learning.

Figure 2 shows a simplified example of a solution tree with different paths. After selecting a path, the learning module continues with options only related to the chosen branch, even if the branch finally would not lead to a final solution, e.g. because of missing data. At the end of the (partial) solution path, the students must evaluate their solution by entering it into the online module. The process of confirming and continuing versus refining or backtracking continues until the student finds a correct solution. Regardless of their position in the module, students can always enter a new attempt for the final solution, to prevent them from having to wade through the rest of the module as soon as they experience the “aha”-moment.

We consider our concept a fine example of intra-exercise adaptivity as depending on the answers and progress of the student, other solution paths are presented that might explore completely different parts of the solution space or that progress at a smaller or faster pace through a similar part with the solution tree.

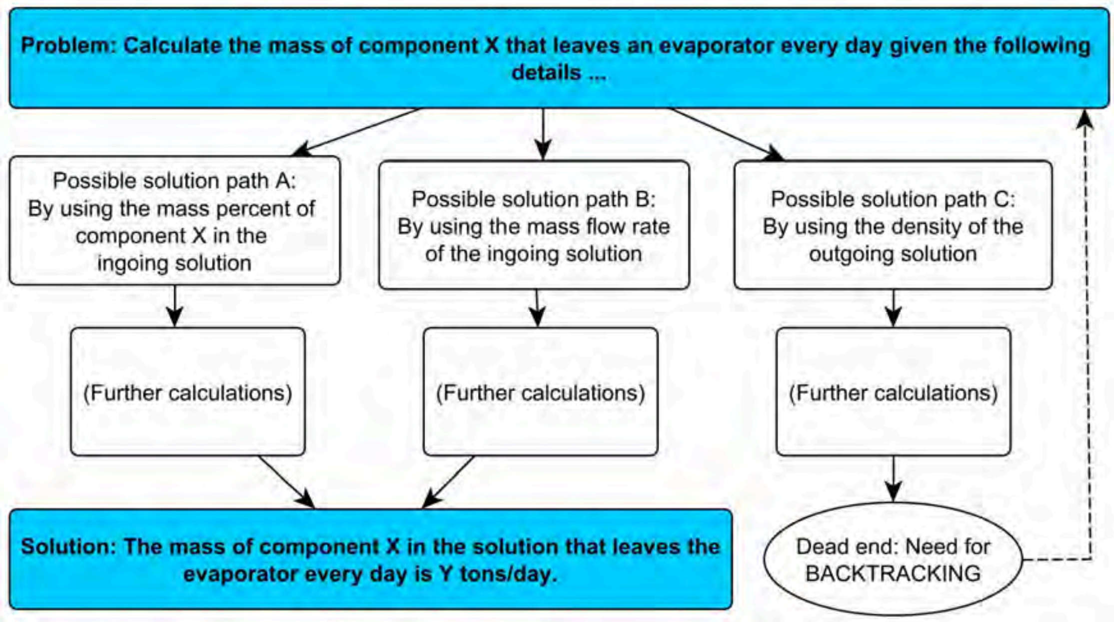

Figure 2: Simplified example of an adaptive solution tree

5 REPORTED EFFECTS

To determine the effectiveness of the online learning modules, we asked all students of the first bachelor year (n = 194) to voluntarily fill in a questionnaire. Most questions used a likert scale, four questions were multiple-choice and two open-ended. Because usage of the modules was also voluntary, some questions were different depending on the number of modules used. 101 students responded, resulting in an overall error margin of 8,90% with a confidence level of 99%. We categorized three groups: no modules used (*zeroMod* group, 41 respondents), one module used (*oneMod* group, 13 students) and two or more modules (*moreMod* group, 47 students). Because the oneMod group consisted of only 13 students, we decided not to withhold this group. In a lot of the domains the students in *zeroMod* and *moreMod* answered similarly, except for the questions in Figure 3. The chances of failing the exam, and being dissatisfied with the results are almost double In the *zeroMod* group compared to the *moreMod* group. This can probably not be solely attributed to using the online modules as students in *zeroMod* probably also practice less when off-line. However two facts at least give an indication of the perceived value of the modules: 1) that 17% of the *zeroMod* group regrets not having used more learning modules and 2) that 34% of the *moreMod* group is convinced that they got a better grade thanks to the modules.

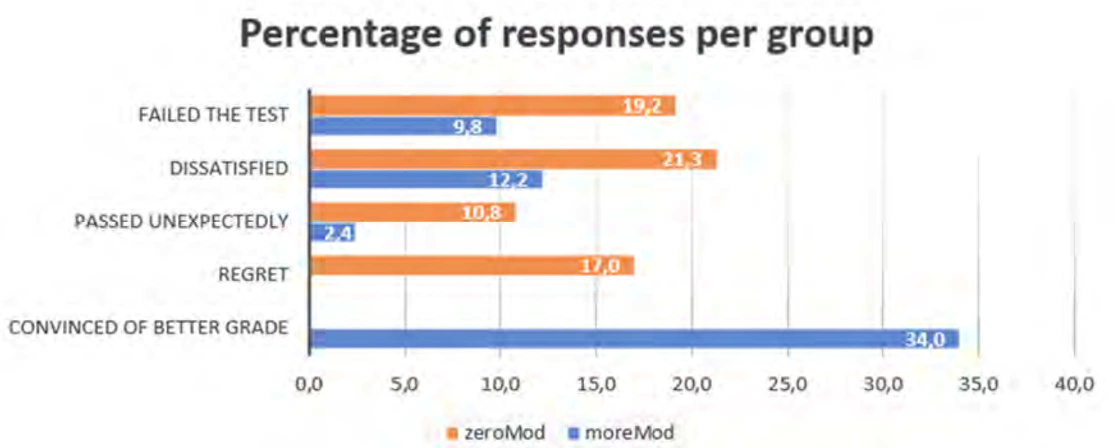

Figure 3: Different answers between zeroMod and moreMod group

We also asked questions similar to Göller et al. (Göller et al. 2017), where 80% of their users found the tool with multiple solution paths helpful in understanding the mathematical concepts, and 40% stated that without the tool they would not have passed the exam. Table 1 shows distinctly lower figures for *moreMod*: 46,3% resp. 4,8%. Looking at the students who barely passed the test and thus need to learn more, this rises to 60% resp. 20%.

	moreMod	*moreMod* barely passing	Göller et al.
Found the tool helpful	46%	60%	80%
Not passing test without tool	5%	20%	40%

Table 1: Reported effect on learning

Further qualitative support could be found in the open-ended questions. The students praised the format in comments as '*Step-by-step guidance'* and '*You can get help and informative feedback when stuck*'. One student put it this way:

> *"I find the online modules very useful because I can clearly see the steps here and I also learn a lot from them."*

The immediate feedback and the proposed proactive approach with hints ensure a good pace in practicing and solves challenges commonly associated with remote learning, where students might drop out of frustration when struggling and void of help or feedback.

Regarding the concept they wrote: '*You are encouraged to search for solutions yourselves'* and '*It encourages logical thinking'.* This fits well in a blended context where you can subsequently challenge the students in-class. The free flow is also appreciated: '*You can skip the feedback steps and just enter the final solution*'. Despite our observation earlier that *only* handing out model solutions does not help students in becoming better problem solvers, students still value them: '*The structured example reports at the end.'*

6 THREATS TO VALIDITY AND FUTURE WORK

A first threat is the socially desired behavior with students unconsciously giving the answers that please their tutors. More important is that we asked about their opinion without really measuring the effect, e.g. whether they think their problem-solving skills improved. To tackle this we will look at the rubrics presented by Docktor et al. (Docktor et al. 2016) and the quantitative measurement of Voskoglou and Perdikaris (Voskoglou and Perdikaris 1993). Another threat is that we tried to let all students participate whereas the central idea of the modules and adaptivity in general, is that only the students who really need it, would use the modules. It is however more likely that the results will only improve when only the correct target groups use the modules. Complaints such as "*It takes too long", "I don't need the modules"* would then disappear.

We also plan further improvements, notably adding more intra-exercise paths, particularly in applying backward thinking, i.e. recoiling from the desired end point to the start; in tracking progress throughout the solution tree and in giving timed hints. The idea is to make estimations of the time needed to progress to a certain state, and to pop up a hint box (with spoiler alert) "*Do you want a hint on topic X".* This somehow resembles the approach by Harskamp and Suhre where students can ask for hints (Harskamp and Suhre 2007), but our approach is proactive instead of waiting on the initiative of the student.

7 CONCLUSION

This paper presented a deconstruction of problem-solving into a non-linear schema consisting of a toolbox of eight building blocks that expands upon previous work with typically four of five basic blocks. The scheme was introduced in a complementary approach for on-campus exercise classes and online learning modules with a focus on consistent reflection on the usage of the building blocks and targeted at blended learning. The intra-exercise adaptivity and multi-path solution trees support divergent thinking and provide the right level of feedback to ensure that students are able to reach a solution.

A survey with 101 respondents out of 194 invites shows that the chances of failing for the tests decreased strongly for students who used at least two modules compared to students who didn't use any modules. The open questions gave further qualitative evidence on the effectiveness of the approach, supporting the claims of the authors to expand the approach. Follow-up research focuses on optimizing the existing modules, developing more developing more modules. Assessing more formally the long-term effects, i.e. the actual increase in problem-solving skills, is also still needed.

8 ACKNOWLEDGEMENTS

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SHAPING A SUSTAINABLE FUTURE THROUGH INTEGRATING SUSTAINABILITY, CREATIVITY AND ENTREPRENEURSHIP IN ENGINEERING EDUCATION AT AALTO UNIVERSITY.

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Conference Key Areas: *3. Engineering Skills and Competences, Lifelong Learning for a more sustainable world. 16. Other Topics in Engineering Education.*

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ABSTRACT

This paper reports the authors' experiences integrating sustainability, creativity, and entrepreneurship in engineering education at Aalto University under the project called the Aalto Co-Educator team. The Aalto Co-Educator team was formed to support the university strategy application into education through three main actions: course development, curriculum development and competence development. The goal of this paper is to share engineering educators' experiences in providing sustainability, creativity and entrepreneurship education to engineering students in a rapidly changing nature of work.

Introduction

Competence requirements for engineering graduates are in transition due to a rapidly changing world and global challenges (e.g. Fomuyam, 2019; Hadgraft, Kolmos, 2020; World Economic Forum, 2020). Aalto University has adopted a strategy that addresses these challenges and aims to shape a sustainable future[2].

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[2] For more information about Aalto University strategy, check www.aalto.fi/en/strategy

The strategy defines three cross-cutting themes: *Solutions for sustainability*, *Radical Creativity* and *Entrepreneurial mindset*, with the goal of impacting all university activities, including research, education and operations. This paper discusses the experiences in integrating these themes into education through a project called the Aalto Co-Educator team[3]. The study sheds light on activities at all levels in the university organization from university top management to schools, programmes, and courses.

University level – Appointing and resourcing a task force

Strategy implementation in an autonomous and self-steering university organisation is not possible using a top-down approach alone. Instead, strategy implementation activities are needed at all levels of the organization. To address the strategy implementation challenges related to education, Aalto University set up the Aalto Co-Educator team project in August 2021. The project team members comprised of teaching development experts with foci in sustainability, entrepreneurship, creativity, collaborative teaching in courses, and experts in programme development. Aalto University works on 2-year study periods. The next period will cover 2024 (autumn) to 2026 (spring). The program-level planning for the 2024-26 study period ends during the 2023 fall term while the detailed course planning continues in 2024. The project is working towards integrating the three cross-cutting themes into the 2024-26 study plan with pilots and development work ongoing in 2021-22.

Aalto University consists of six schools: (1) Arts, Design and Architecture, (2) Business, (3) Chemical Engineering, (4) Electrical Engineering, (5) Engineering, (6) Science. In these schools, education happens in several independent bachelor, master and doctoral programmes. While programmes and courses have significant autonomy and can independently define their intended learning outcomes, the Aalto Co-Educator team's goal is to ensure that the integration of the cross-cutting themes happens in practice and that students receive sufficient education in sustainability, creativity and entrepreneurship.

Aalto Co-Educator team activities

Once established, the team needed to elaborate on the meanings of the three cross-cutting themes in education. The need for translating the strategy language into teaching terms became evident during the piloting stage when the team was working with teachers on courses and with programme directors on programmes. The team

[3] For more information about the Aalto Co-Educator team, check www.aalto.fi/en/co-educators

needed to develop answers to questions such as: What is radical creativity? What do we mean by sustainability? How are these themes relevant to teaching?

Formulating responses to these questions was an iterative process between the team and the teaching faculty. The first iterations of this process analysed the competencies associated with the three themes. This phase was based on literature (e.g. Wiek, Withycombe, Redman, 2011) and practical experiences of the team members in integrating the themes in education.

One intermediate stage of the evolution is visualized in Figure 1 below. This version presented one Intended Learning Outcome (ILO) for each of the cross-cutting themes (violet circles): Understanding and addressing sustainability-related challenges, driving viable solutions to open-ended challenges (entrepreneurial mindset), and being able for creative teamwork (radical creativity). These high-level themes have then been broken down further into more detailed topics - e.g., systems thinking, futures thinking (Wiek, Withycombe, Redman, 2011), experimenting and decision making. The interesting observation here was that the breakdown of each of the 3 top-level themes resulted in the same or very similar topic breakdown, supporting the notion that the three cross-cutting themes can and should be managed together for inclusion in education.

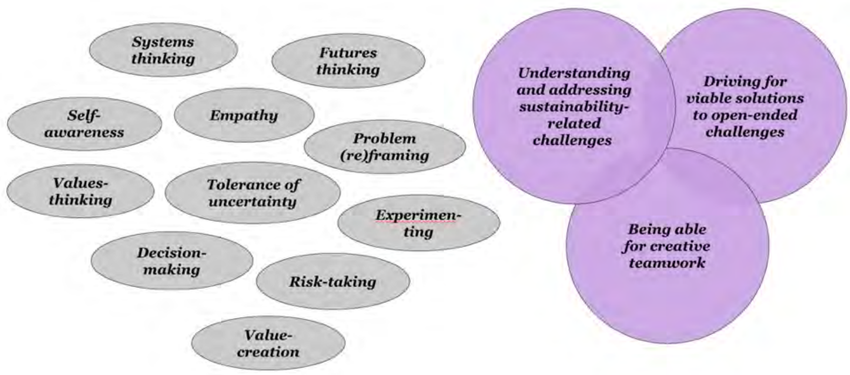

Figure 1. Competencies under the cross-cutting themes

After understanding the main topics derived from the cross-cutting themes, the goal of the Aalto Co-Educator team was to establish intended learning outcomes (ILOs) for programmes and then for courses. In this process, the team noticed how these three topics presented clear overlaps in terms of learning goals and how counterproductive it would be to consider them separately. For example, ‘ability to identify challenges, ideate, experiment, and implement feasible, user-centric interventions’ resonate both with the entrepreneurial mindset and radical creativity. By building broader ILOs that encompass the three cross-cutting themes, the team managed to develop a “language” that facilitated the process of applying and integrating these topics into programmes and courses. This result is shown in Table 1 (next page).

Understanding and addressing sustainability-related challenges	**Driving for viable solutions to complex challenges**	**Nurturing creativity in teams and individually**
Knowledge of sustainability-related challenges and their systemic nature. Ability to contribute with one’s field-specific expertise to shaping a sustainable future.	Ability to identify challenges, ideate, experiment and implement feasible, user-centric interventions. Capability, courage and perseverance for acting in an environment of risks and uncertainty.	Ability to provide alternative framings and seek novel perspectives. Ability to participate in and facilitate creative processes and to collaborate across disciplines.

Table 1: Cross-cutting themes integrated into three ILOs.

Parallel with establishing how the cross-cutting themes are translated into ILOs, the Aalto Co-Educator team started to build connections with different levels in such a complex and distributed organization. Table 2 lists the types of activities that the project team engages in at different levels of the university.

<table>
<tr><th>University level</th><th colspan="2">Activity</th></tr>
<tr><td>University</td><td colspan="2">Strategy for tackling future challenges, including the identification of the three cross-cutting themes.

Setting up the Aalto Co-Educator team to drive strategy implementation into education.</td></tr>
<tr><td>School</td><td colspan="2">Instigating and (re)defining the necessary educational programs: BSc, MSc, PhD.

Active dialogue with school education leadership.</td></tr>
<tr><td>Programme</td><td>Defining programme learning outcomes and curriculum.

Active dialogue, ideation and concrete ILOs definition in cooperation with program management and teaching team.</td><td rowspan="3">Competence development support for teaching staff in different roles.

Pedagogical course for course and program staff, support for teamwork.</td></tr>
<tr><td>Course</td><td>For selected course, (re)define course content to include relevant topics supporting the three cross-cutting themes.

Course co-design and co-teaching together with course staff.</td></tr>
<tr><td>Teacher</td><td>Supporting teachers in practical teaching activities.

Teaching method development.</td></tr>
</table>

Table 2: Aalto Co-Educator team activities in the university.

Figure 2 below represents how the Aalto Co-Educator team conceptualises its work: teachers develop their skills in competence development, which are transmitted to students in programmes and courses. The implementation of the strategy into education aims at better preparing students for shaping a sustainable future. In practice, integrating sustainability, creativity and entrepreneurship in education, and therefore promoting student learning in these topics, is the focus of the Aalto Co-Educator team in three different types of actions. (1) Programme Development, where the team collaborates with programme directors to define the program ILOs and curriculum (2) Course Development, where the Aalto Co-Educator team works closely with teachers to ensure that the programme-level ILOs are implemented in the planned courses and (3) Competence Development, where we support pedagogical training experts and develop one course for the formal pedagogical training track for university teachers. We will describe each of these three types of activities over the next paragraphs while also pointing out examples.

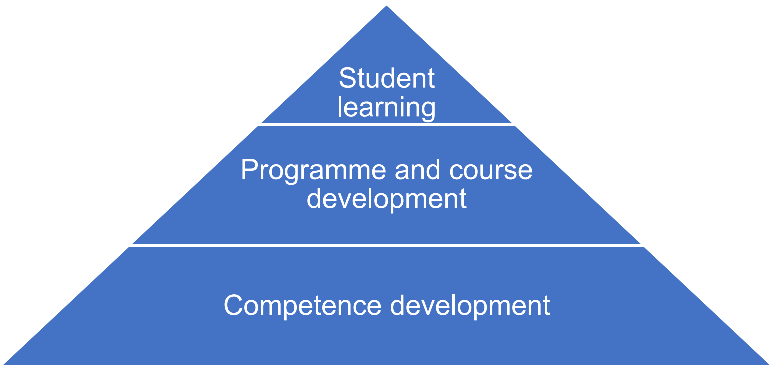

Figure 2: Aalto Co-Educator team works towards student learning

Programme development

At the programme level, one commonly applied solution for introducing a new topic is to introduce a new course. However, the Aalto Co-Educator team aims to integrate sustainability, creativity and sustainability as meaningful and fitting elements in the curriculum courses. We hypothesise that as a separate course, the themes will remain separate while as part of the core courses, the themes merge into the field-specific expertise.

While in course development, the Aalto Co-Educator team works with individual teachers on their courses. In programme development, the team takes a holistic view of the programme: its objectives, learning goals and courses. Similar to what was described in course development, the goal is to identify meaningful connections between the programme objectives with sustainability, creativity and entrepreneurship.

In practice, the Aalto Co-Educator team engages in discussions with programme managers and the teaching team to collaboratively identify how the connections between sustainability, creativity and entrepreneurship can happen. Examples of tools used by the Aalto Co-Educator team in programme development are, for example, curriculum mapping and workshops with the teaching team. Below is one short example of refining ILOs with the support of the Aalto Co-Educator team.

Case example: Programme dialogues in an engineering school

One of the four engineering schools at Aalto University decided to have dialogues with all the programme directors at the school. To date, the dialogues with the directors have continued as a) a reflection dialogue with a programme director, b) facilitation of a workshop with the directors of the majors in a programme, c) sustainability integration in a central high-reach course.

Course development

The actual implementation of the university strategy, and its three cross-cutting themes, into education happens in courses. The strategy does not mandate that every course implements some or all cross-cutting themes. Instead, program development should identify a (small) set of relevant courses that will be used to deliver the program-level ILOs.

The Aalto Co-Educator team works together with the course teaching team to identify meaningful connections between the course content and practices with sustainability, creativity and entrepreneurship. In practice, this means that the Aalto Co-Educator team meets with the teacher(s) in charge of a course for a discussion on what the course learning objectives are and how sustainability, creativity and entrepreneurship can be integrated. An important note is that the teacher(s) in charge have a key role in establishing the connections, while the Aalto Co-Educator team takes the role of facilitating the discussion.

After the discussion with the teaching team, the activities for integrating sustainability, creativity and entrepreneurship in the course are planned. One option is that one of the members of the Aalto Co-Educator team member teaches one (or more) sessions in the course (co-teaching). Another option is that the Aalto Co-Educator Team identifies an expert in the university (or outside) to teach the course. A third option is that the Aalto Co-Educator team only joins the planning of the activities (co-development), where the teaching team takes responsibility for teaching elements of sustainability, creativity, and entrepreneurship in the course. Below, we briefly present one example of a course supported by the Aalto Co-Educator team.

Case-example: Hands-on project course in electronics.

The *Sähköpaja* (Electrical Workshop in English) course is an innovative project course, which is mandatory for the majority of the students at the School of Electrical Engineering. The student teams ideate, develop and build an electrical device during the course. The topics integrated into the course are a prototyping session, exercise and reflection to support the visualizing and testing of an idea as topics of entrepreneurial mindset and radical creativity themes. Sustainability topics presented were environmental impacts associated with the life cycles of electrical and electronic products and the eco-design tools applicable. The student teams reflected upon the themes in a separate session.

Competence development[4]

Building competencies in sustainability, creativity, and entrepreneurship for the teaching staff at Aalto University is a goal shared by the Aalto Co-Educator team and pedagogical specialists across the university. The Aalto Co-Educator team provides support for teachers on these topics and how they can be integrated into their courses and programmes. In addition to that, the Aalto Co-Educator team collaborates with pedagogical specialists from different schools in co-design and co-execution of school-level teaching development activities.

One example developed by the Aalto Co-Educator team is the development and execution of the course Sustainability in Teaching, as part of the pedagogical training for teaching staff at Aalto University. The 3 ECTS course runs twice a year and offers up to 20 teaching staff members the opportunity to identify and apply different approaches to integrate sustainability into teaching. Some of the topics covered in the course are the relevance of sustainability for participants' specific fields, identifying key areas of sustainability relevance, sustainability in higher education, key competencies of sustainability education and how to cope with student anxiety regarding the sustainability crisis. The course has received positive feedback from teachers over the last few years.

Lessons from integrating sustainability, creativity and entrepreneurship into courses and programmes

Implementing a university strategy in education does not come without challenges. However, the experiences of the Aalto Co-Educator team reported in this article can serve as guidance for other engineering educators who aim to integrate

[4] For more information about competence development in the Aalto Co-Educator team, see Schönach, Jaakkola, Karvinen (2023).

sustainability, creativity and entrepreneurship into their educational programmes. Below, we summarize our key takeaways for fellow educators.

- *The translation from strategy into education is not straightforward*. Collaboration with programme staff and teaching faculty was essential. Together, we translated the strategy terms into the language and terms used in the teaching development in the form of ILOs, content topics and teaching methods.

- *Staff support is an ongoing need.* Even after the Aalto Co-Educator team managed to translate the strategy terms into ILOs, teaching staff could not simply implement them. Instead, it required further resources and capabilities from the Aalto Co-Educator team on how to meaningfully integrate the cross-cutting themes into education.

- *The three levels of support - course, curriculum and competence development - offered by the Aalto Co-Educator team proved to be useful for tailoring the support for different staff needs*. For example, teachers in charge of courses and programme directors have different needs (and reach) in terms of the integration of new topics into their teaching. We discuss these three different levels in the next items.

- *Curriculum development proved to be essential to get the mandate and priorities from the schools' teaching leadership*. The dialogue with the programme directors called for thorough background work on the programme goals and courses. Having an overall picture of the programme content and the strategy terms in the form of ILOs facilitated the discovery of meaningful connections between the themes and programmes.

- *Course development is the place where the integration of sustainability, creativity and entrepreneurship happens in practice*. In other words, students meet these topics in practice within the actual coursework. Thus, course integration needs to be directed at the courses with a high reach of students and/or mandatory courses, due to being a resource-intensive activity.

- *Competence development, in the form of a pedagogical course, has proven to function as a platform for competence development*. More specifically, it strengthens the teachers' confidence in teaching sustainability topics and builds connections within the teacher community.

In conclusion, as the Aalto Co-Educator team activities will end at the end of 2024, we acknowledge that the journey of educating engineers on sustainability, creativity, and entrepreneurship cannot be restricted to a single project. It requires continuous support from universities and should be viewed as an ongoing, iterative process. Therefore, we encourage academic institutions to consider the long-term horizon of their support systems, beyond the conclusion of specific projects or teams.

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CONTINUOUS ASSESSMENT IN ELECTRICAL POWER ENGINEERING FOR MARINE ENGINEERS

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Conference Key Areas: *Curriculum development, Innovative teaching and learning*
Keywords: *Electric power circuits, Electric power systems, Learning outcome*

ABSTRACT

To tackle the climate challenge, all sectors need to contribute, including electrified shipping. Electrified shipping is not only propulsion but also loading and unloading equipment. This transformation requires increased skills and understanding of electric power engineering for the personal onboard, not least for the marine engineers. Therefore, a changed in the curriculum was needed. However, when more theoretical course content was added to two consecutive courses, the student view and passing rate dropped. Although the student view improved quickly, the passing rate recovered slower. To address this issue, continuous assessment was introduced to counteract the drops. The aim of this study was to evaluate the theoretical parts and determine if continuous assessment could contribute to improve student learning and increase passing rate. The students expressed satisfaction with the changes, and the passing rate has increased. Most students also claimed that they learned more compared to standard assessment methods.

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1 INTRODUCTION

The trend of electrification of propulsion (Kersey, Popovich, and Phadke 2022) has also come to the shipping industry even though it is delayed compared to many others part of the society. This is mainly due to technical challenges like size, weight and cost of batteries (Kersey, Popovich, and Phadke 2022), but now the development goes fast and the number of fully electrified ships worldwide is increasing rapidly, especially in the Nordics countries (Tarkowski 2021). But it is not only the propulsion that has become electrified (Wärtsilä 2022), also the loading and unloading of equipment is electrified.

The disruptive electrification transition in the shipping industry put new requirements on the needed skills for all that work in the shipping business, like Marine engineers. A curriculum development project was done in the academic year 2017/2018, in two consecutive 7,5 credit courses in the Marine engineer education at Chalmers University of Technology (Chalmers), based on the Standards of Training, Certification and Watchkeeping (STCW) A-III/1, A-III/2, A-III/6 and A-III/7 (International Maritime Organization 2019). The purpose was to meet the new requirements that the electrification demands while still fulfilling the STCW requirements. In the first course the focus was more on general knowledge on how to handle basic models of electric components, like resistances, inductances, and capacitances, and how to solve more extensive problems. This was done to prepare the students for the more complex systems that are expected on electrified ships, and which will be harder to grasp intuitively. The second course emphasises on models of actual electric components, like electric machines, cables, and power electronics converters, but also include systems aspects on components interaction as well as high voltage. A stronger component influence on system behaviour is expected to be needed to handle the rapid development in the areas of electrification. High voltage was also included as more land connections as well as systems on board are above 1 kV.

The marine engineer students are unique as a student group since they often have more applied view on knowledge and therefore often has low interest and experience of theoretical studies as they are focusing on professional degree (Hindhede and Højbjerg 2022). Therefore, they often do not have a developed and/or an individually adapted study technique which is challenging for the academic teachers (Hindhede and Højbjerg 2022). During the last decade the interest of potential students to the marine engineering program has decreased and since the academic year 2015/2016 all eligible students has been accepted. This has led to a large spread in pre-knowledge and in study techniques, despite no change in admission requirement. The number of students in the course has varied over the studied period between 7 and 53 with a mean number of 31 and 38 for respective courses.

The passing rate of the two courses dropped at the same time as the curriculum development was done, which initiated a development of the assessment process. The desired outcome of the development was to:

- Get the students to work continuously throughout the course.
- Increase the passing rate during the first year of the course.
- Assess knowledge rather than skills.
- Increase the interest in getting feedback, they do not learn from their mistakes.

In addition, there is an extra requirement to show that all learning outcomes was assessed due to the certification according to the SCTW requirement.

A system of continuous assessment was introduced in an attempt to meet the above mentioned goals. Continuous assessment is an ongoing process of monitoring, evaluating, and providing feedback on the progress of student learning over time. It is known to improve student learning by providing ongoing feedback to students and helping them to identify their strengths and weaknesses, so they can make adjustments to their learning strategies (Hattie 2012). It can also encouraging students to stay engaged and focused throughout the course (Rosadoa et al. 2022). Moreover, it can also help the students in breaking down the learning into, for them, more manageable parts and to take ownership of their learning by enable them to set goals and monitor their progress over time. The outcome of continuous assessment has shown to lead to better grades, a higher passing grade and improved engagement in course activities (Korhonen et al. 2022). However, there are drawbacks (Hattie 2012), like time-consuming for both students and teachers, puts higher constant pressures on the students and it might limit the learning with a too narrow focus on the assessment in the learning situation.
The main outcome of this paper is to find out to what extent continuous assessment can support marine engineering students to meet the new requirements that the electrification demands through more advanced studies in electric power engineering.

2 METHODOLOGY FOR REVISION AND EVALUATION OF THE ASSESSMENT

The first course, basic electric power circuits course (BEPC), is given in the second half of the first semester during the first year. The second course, Electric Power System and Component course (EPSC) is given in the first half of the first semester in the second year. The implementation was done step-wise, first in the BEPC due to a more pressing situation and then in the EPSC.

2.1 Basic Electric Power Circuits

Previously the assessment was three laboratory work and a written final exam. During an intermediate period of two years, three small exams were provided during the course, giving bonus points to the written final exam. Since 2020/2021 the written exam is divided in three parts, A) on DC circuits, batteries and cables, B) on AC circuits and C) on three phase system, the DC machine, and transformers. Each part counts for two credits each. The three laboratory work are kept as before and gives 1,5 credits. Students that have passed one part, does not have to remake that part. The final grade is determined by the total points of the three parts, but at least 50 % is required on each part. The three laboratory work are all 4 hours long and has been the same since 2017/2018, first part is on DC, the second is on AC and the DC-machine and the third is on the three phase system and the transformer.

2.2 Electric Power System and Components

Previously, the assessment was divided into three parts, five occasions with laboratory work, three short hands-in related to regulations at sea and a final written exam. Since 2022 the written exam is replaced by three hand-ins. To verify that the students have answered the hand-ins themselves there is an oral follow-up. If the students pass the follow-up, they get grade 3 on that hand-in, which is the lowest grade for pass. For higher grade, a more traditional oral assessment is done. The five laboratory works are the same since 2017/2018: the first is on the synchronous generator and generator operation in a small power system, the second is on the asynchronous motor including starting methods, the third is on power electronics and converters, the fourth is on high voltage phenomena and the final is on cable sizing and protection settings.

2.3 Evaluation

For the entire studied period 2013/2014 to 2022/2023 the answers on the anonymous written standard evaluation form of the university are used. The data from these forms are used for the long term and trend studies. As completement an extra anonymous written evaluation was done during 2022/2023 just before and after the EPSC. Data regarding grades and passing rate were retrieved from the national student administration system, available via the public principle.

3 RESULTS

In the written standard evaluation form, there is one question where the students are asked to rate the overall impression of the course, from grade 1 very poor to grade 5 excellent. In Figure 1 the average overall impression of the BEPC and EPSC together with the average of the yearly overall impression of all courses in the program are shown.

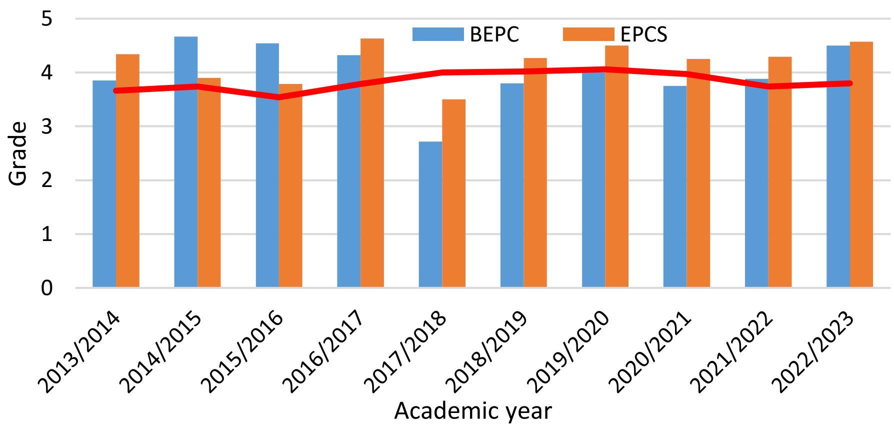

Figure 1. Average overall impression of the BEPC and EPSC and the yearly average for the marine engineering program at Chalmers. The scale is from grade 1 very poor to grade 5 excellent.

As can be noticed in the figure there is a significant drop in the overall impression for year 2017/2018. That year the teaching staff and the examiners of both courses were replace together with that the curriculum was developed. The large drop was restored the year after and the courses has returned to be better than the program average, though it took longer time for BEPC to recover.

In Figure 2 the grade distribution for the BEPC is shown. The result is the total after the three possible attempts to pass the exam(s) of the year they registered for the course. The results are the combined distribution of all the three possible exam occasions during each year. The grading scale is that grade 5 is for between 100 % and 83 % of the total number of points, grade 4 is for between 83 % to 67 %, grade 3 for 67 % to 50 % and the student fail, grade F, if the summation of the points scored on the tasks are below 50 % or not all parts has at least 50 %. As can be seen in the figure the failure rate has increased from 2016/2017 and the distribution of students with the highest grade has also decreased compared with the earlier years. As mentioned before, in 2020/2021 the final exam was divided into three smaller exams and from Figure 2b) it can be noticed that the failure rate has decreased from 2020/2021 and the number of students that got the highest grade have increased, at least in study year 2020/2021. As can also be noticed in the figure there are some students that have passed two and one of the three exams. This means that these students can focus on the remaining exam or exams and do not need to study for the part/parts they have already passed. It should be highlighted that the number of students in the course in study year 2018/2919 was much lower compared to the other years.

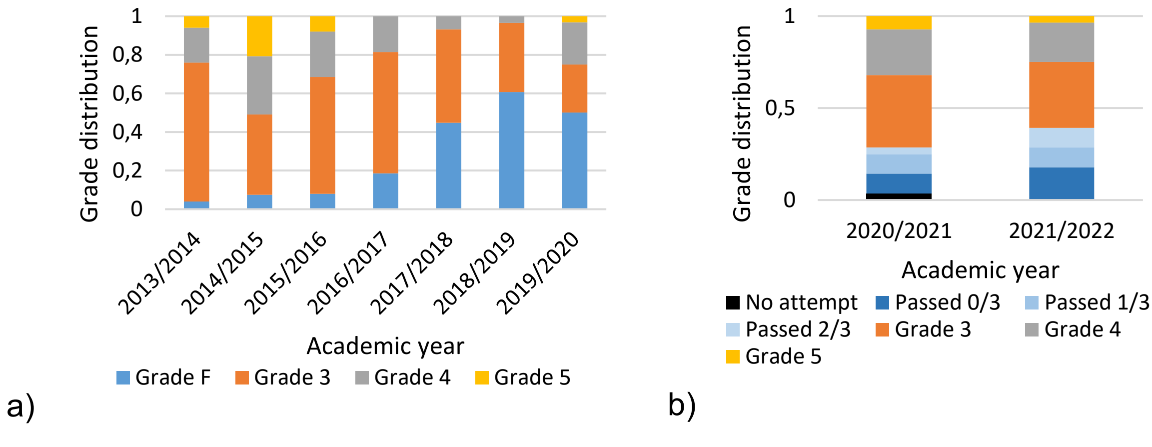

Figure 2. Grade distribution for the BEPC, where a) is for 2013/2014 to2019/2020 and b) is for 2020/2021 and 2021/2022 where continuous assessment was applied.

In the second course, EPSC, the assessment did not change until 2022/2023. In Figure 3 the grade distribution can be seen. The result is the total after the three possible attempts to pass the exam(s) of the year they registered for the course. However, not all students utilize that possibility. Students that pass the course after the first year after registration are not included in the statistics. It can clearly be seen that the passing rate decreased 2017/2018 due to the content change in the course. In 2022/2023 there was a significant raise in the passing rate and the students that failed did not even tried to solve any of the hand in assignments. The outcome of the new assessment has meant fewer fails and more students with grade 3, but not more students with grade 4 and 5. This probably means that the system does not contribute to grade inflations. Around 80 % of the students stated that they got the grade they aimed for.

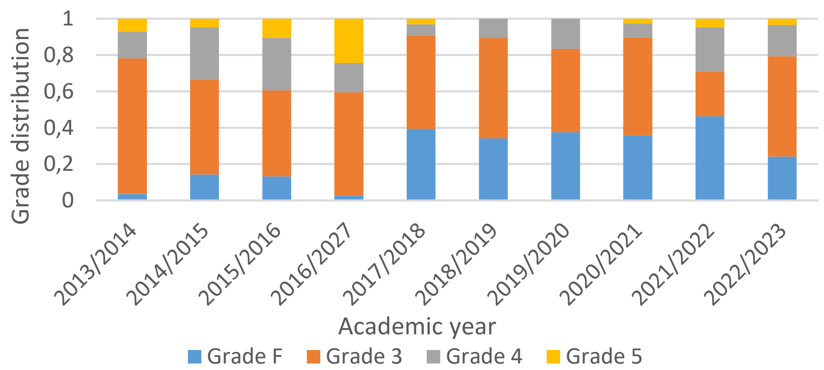

Figure 3. Grade distribution and failing rate for the EPSC

There are two other factors that could contribute to the increased failing rates from 2017/2018 in the two courses. One is that from this year all eligible students were admitted to the program, which means that some students were admitted with low merits. The other factor is that the number of students that has been admitted to the program has been dropping between the years 2014/2015 to 2018/2019 and then the number of students has slowly increased, but only to approximately half of the number of students that was admitted in 2014/2015. This means that the number of students in the courses are low and some of these students have low merits. This could contribute to a decreased passing rate and lower grades of the students. Unfortunately, it is not possible to differentiate these effects form the effect of a new course setting and teachers.

In Figure 4 the student view on the relation between the assessment and the learning outcomes are shown. The question deals also with the expectations of the assessment as it has a high correlation with the result of the assessment.

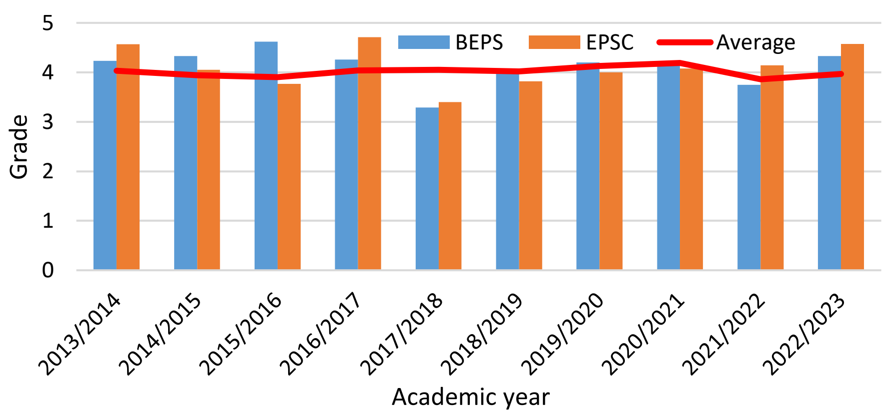

Figure 4. Students grade (1-5, where 5 is the highest) on however the assessment of the course is related the learning outcome of the course.

Overall, the student thinks the assessment is suitable for both the courses. There is also here a drop in 2017/2018 followed by a recovery that levels out, but for the last year there is another step in the right direction.

It can be seen that students prefer the continuous assessment, but the different set-ups fit different students. As was expressed by a student:

> *"Good new take on the exam, it promotes learning!"*
>
> Anonymous student taking EPSC in 2022/2023, translated from Swedish by the authors.

On a direct question if the student learned less, the same or more due to the new set-up in the EPSC, 95 % stated that they learned more and the last 5 % stated that he/her learned less. The claimed higher degree on learning and also higher passing rate, see Figure 3, can be explained by the reoccurrence of learning opportunities, during the teaching, at the hand-ins and then as preparation of the oral follow up. Another explanation is that the students were stressed for the oral follow-up, so they did not dare to show up unprepared. Almost half of the students claimed that the oral follow-up was stressful, but some also claimed that written exams can be stressful.

4 DISCUSSION

When introducing continuous assessment in the two courses also the structure of the courses was adapted for this. The courses were divided into smaller parts and all teaching elements that supported the students learning of one part was given before the next part was started. The assessment of the part was done approximately a week after all teaching of the part ended. It was done in this way because the later parts build on the previous parts in the course. Since the assessment is close to the end of the previous part the students should have a good understanding of it so they can use it as the base of the following part. In this way the course structure helps the students with a preferred order of learning. The division into smaller parts also means that the amount of material that needs to be studied for each assessment is smaller and this can make it easier for the students since they have a limited part of the course material to study for each assessment. For the BEPC, from 2020/2021, the students also get each part reported individually and after completing all the parts they get a final grade on the course. This means that if a student fail on one part, the student only needs to study that part again and take the reexam for that part of the course. This helps the students to know which part and which material to focus on. From Figure 2 and Figure 3 it can be seen that the failing rate increased when the curriculum was developed, but it has decreased since. From Figure 4 it can be seen that the students thinks that the assessments tests that they reach the intended learning outcomes of the course and if the students mark this question with this high numbers, it usually means that they also think that the assessment is fair. From Figure 1 it can also be noticed that the overall impression of the courses is good and if the grading of the course is this high it usually means that the students like the course. It is good courses with fair assessments, but difficult.

The continuous assessment provides continuous feedback on the progress of the student, especially related to the passed parts. However, for the not passed parts it is more problematic, apart from the actual result, especially for the BEPC. In the course the students get an example of a solution for the exams and are invited to discuss their solution with a teacher, but no one has ever done that. In the EPSC the students need to, and do, address the not passed part to not fall behind in the assessment process.

Moreover, using different assessment methods can provide a more comprehensive and accurate picture of an individual's abilities and strengths (Suskie 2018). Therefore, it's important to choose an appropriate range of assessment methods for everyone, to help them maximize their learning and achieve their potential.

Oral communication, trained in the oral follow-up, is essential for marine engineers, particularly in situations where safety and efficiency are paramount. By prioritizing effective oral communication, marine engineers can perform their duties more effectively and minimize the risk of accidents and other safety incidents (Ahmmed 2018; Øvergård et al. 2015). But training in verbal communication is also important for the sometimes stressed psycho-social environment onboard, which may occur due to fact they work close together for longer periods of time (Thorvaldsen and Sønvisen 2014).

5 CONCLUSIONS

The developed assessment methods make/forces the students to work continuously throughout the courses and might have contributed to the increased passing rate. The oral follow-up focuses more on knowledge then the skills and practice technical oral communication but is quite stressful. It also gives an opportunity to give direct feedback on any misunderstandings in a way that is hard to do in writing. At least in the EPSC the students really read and sometimes even discuss the short comings in their work.

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ON A COMPUTER SCIENCE MASTER PROGRAM FOR SUSTAINABLE DEVELOPMENT

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***Conference Key Areas**:* Embedding Sustainability and Ethics in the Curriculum, Engineering Skills and Competences
***Keywords**:* Computer Science, Sustainable Development, Multi-Disciplinary Contexts, Approaching Ethical Aspects, Self-Reflection

ABSTRACT

Sustainable development and the UN's Sustainable Development Goals have been pointed out as crucial for our common future, addressing several aspects of a world to be considered as sustainable. From a university perspective it is certainly interesting, and important, to see how research and education contribute to that context, which may be seen from both disciplinary, and multi-disciplinary perspectives.

A one-year Master Program in Computer Science for Sustainable Development, at Kristianstad University (HKR), Sweden, has a background in the UN's Agenda 2030, and in statements, claiming that 'at the edge'-techniques, from areas such as Artificial Intelligence, and Datamining are crucial to approach each and one of Agenda 2030's 17 Sustainable Development Goals. With this background, that Master program, was initiated to provide, for students at a master level, challenging disciplinary subjects, as well as an interesting and valuable context to contribute to, with their technical skills. To furthermore approach the students' maturity in the field, the program is supported by courses regarding, on one hand (1), Sustainable Development, and how Computer Science generally may contribute, and on the other hand (2), advanced projects where concepts and techniques shall be practiced within research contexts. It shall also be mentioned that the program is open for students internationally, thus bringing further interesting values through the mutual sharing of experiences from international perspectives. This contribution intends to provide an overview of the program, as well as a more in-depth presentation of the two above-mentioned courses.

1 INTRODUCTION

The United Nation's Agenda 2030 was adopted in September 2015, and explicitly pointed out 17 Sustainable Development Goals (the SDGs) to be achieved in 2030. While those goals ([1]) address several critical areas, such as, *No Poverty*, *Zero Hunger*, and Good Health and Well-Being (SDGs 1, 2, and 3), one goal especially addresses cooperation to accelerate the achievement of the SDGs, that is, goal 17, *Partnerships for the Goals*. Today, there exists a number of national as well as regional Sustainable Development Solutions Networks (SDSN) ([2]), and where especially SDSN NE (NE stands for Northern Europe), organizes the northern nations of Europe, including Denmark, Finland, Norway, and Sweden, for cooperative actions in the context of Agenda 2030.

The launch of SDSN NE took place in Gothenburg, Sweden, in February 2016. HKR (the home university of the author) was represented by the author of this paper (amongst others). At that launch, Swedish business and political leaders were invited to participate, along with engaged academics and representatives of several organizations, such as the UN and the Swedish International Development Cooperation Agency ([3]), showing the high ambitions for the SDSN NE, as well as for the Agenda 2030 at large. At that meeting, furthermore, IT was singled out several times as essential to achieving each of the 17 SDGs. Not only was IT mentioned in general, but cross-cutting techniques such as Big Data, AI, and the Internet of Things (IoT) in particular ([3]). It can be mentioned, IT or Computer Science, does not explicitly correspond to any of the SDGs but is nevertheless considered to be crucial for the fulfilment of each of them ([4]).

Meanwhile, at that point in time, the Dept. of Computer Science at HKR (CS@HKR) was struggling with its previous master program in computer science. That program should have a focus on Embedded Systems but was rather diffuse in nature and difficult to get a comprehensive understanding of. It was therefore perceived as a need to revise the master's program in order to have a clearer and more well-motivated structure. The launch of the SDSN NE could in this context be seen as a source of inspiration to revise that master program in a direction towards how Computer Science (and IT generally) may contribute to Sustainable Development (SD). In such as program, concepts of SD would in that case be emphasized, and interesting and valuable techniques addressed.

1.1 Meeting Legal Demands on Sustainability in Education

Regarding this contribution from another perspective, the Swedish Higher Education Act ([5]) clearly states that SD should be considered at the Swedish universities, and that concepts of SD should be included in the universities' various courses. In 2017, to follow up how well the Swedish universities lived up to those directives, a survey was organized by the Swedish Higher Education Authority ([6]). The result showed a rather depressing result ([7]), only about 25% lived up to the directives, and then about 75% (including HKR) needed to do more or less exhaustive work on course design, as well as on administrative routines to improve their approaches towards SD.

Requirements for sustainable development in the computer science programs were generally difficult to relate to. But with inspiration from the launch of the SDSN NE, it was possible to see that there was in fact a lot that could be approached. Moreover, from the perspective of several technologies, approaching the SDGs could furthermore be seen of interest to students as well as to researchers and teachers.

In the light of the above, in September 2017 it was decided that a revised master's program in computer science should have an overarching focus on SD, encompassing interesting techniques to meet SD, and clearly be related to surrounding societal interests. Like the previous master's program, the revised program should be open internationally, with potentials to contribute to additional values regarding SD. The program is a one-year master's program and was provided for the first time in autumn 2018.

1.2 On Prerequisites for Teaching and Learning on SD

According to [8], Higher Education has a critical role in advancing the agenda of SD, and where educating for SD can be considered a natural way to ensure SD. Already since the Stockholm conference in 1972, the significance of sustainability ([9]), in Higher Education has been recognized for its important role in fostering society towards SD. Still, as pointed out by [3], barriers emerges when higher education institutions do not establish incentive systems that promote changes at the individual level. Lack of time, and administrative support, thus, make it difficult to integrate SD in higher education institutions ([3]). The re-designing of curricula is a relatively easy part, but efforts that imply organizational members to hold shared assumptions about SD and take the lead in society demand something else ([8]).

The demands for improvements on SD at HKR, were primarily approached through an investigation into the circumstances of HKR, and suggestions on how to improve ([8]). In a report resulting from that investigation, a pedagogical course for HKR's educators was proposed ([10]), among other things. That course was launched at 2018, piloted with educators from CS@HKR in 2018. It has then been open for all educators at HKR ([11]), thus contributing to inter-disciplinarity, or cross-faculty approaches towards SD ([12]). The course emphasizes SD generally, experience sharing amongst colleagues, and tasks regarding curricula and course development towards SD, all in all to support the educators with capacities for SD teaching and learning at their respective study programs and courses.

2 METHODOLOGY

The one-year Master Programme *Applied Computer Science for Sustainable Development*[1] has as an overall goal that '*the student, after graduation, should be able to work with and lead the development of complex computer-assisted systems with an independent, critical and interdisciplinary overall view, in order to meet the multidisciplinary needs, found in different contexts related to sustainable development*'. To support for this, a structure of the study program must concern aspects on SD, as well as skills in advanced techniques of computer science. Furthermore, to be able to act effectively in contexts of multi-disciplinary challenges, project courses should bind together technical skills and apply those in contexts outside computer science, and with contributions to SD. Furthermore, demands are especially put on master programmes in being research oriented. That is, technique-oriented courses as well as SD-concept-oriented and project-oriented courses must reflect on research themes. An overall structure of the program is illustrated by Fig. 1, and where the timeline of the program follows the numberings of the blocks, and where 'CS methods 4 SD' runs over the whole first autumn semester.

[1] Applied Computer Science for Sustainable Development: One-Year Master Programme - 60 credits, https://www.hkr.se/en/program/computerscience-master

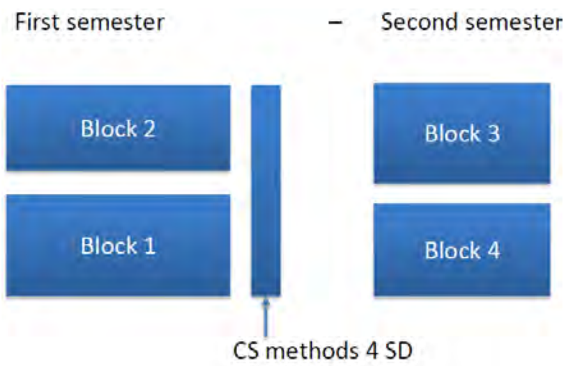

Fig. 1. Outline of a one-year program

Moreover, students should be able to meet challenges where sensor-data in Internet of Things-based systems may reveal, for instance, air quality, or states in agriculture. Data should be collected and withdrawn through methods of datamining and interpreted through AI or Machine Learning. Furthermore, results should be monitored, preferably at handheld devices independent on underlying technology. Also, the communicating data and results should be made secure. Thus, the blocks are furthermore outlined as follows:

- **Block 1**
  - Mobile platform development
  - Wireless communication and security
- **Block 2**
  - Internet of Things
  - Machine Learning
- **Block 3**
  - Project, multi-disciplinary
  - Data Mining
- **Block 4**
  - Thesis Project
- **and also, CS Methods for SD**
  - Generic skills, Science and methodology
  - Self-reflection and self-awareness
  - The context of the Agenda 2030, and Computer Science for SD

This contribution will especially focus on two of the courses that have been given by the author of this paper, that is, *Computer Science Methods and Sustainable Development*, and *Project in Multidisciplinary Contexts*. The structures and main contents are outlined in the sequel.

2.1 Computer Science Methods and Sustainable Development

First, the syllabus of the course[2] clearly addresses the context of SD to the course, and furthermore points out ethical aspects as significant. Second, the course aims to

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[2] Computer Science Methods and Sustainable Development - 6 credits, https://www.hkr.se/en/course/DT580C/course-syllabus

practice generic skills, such as searching and reading scientific material, and make oral and written presentations. The main components of the course are *Lectures*, *Exercises,* and a *Design Project*.

The lectures are supported by literature with focus on general perspectives on SD[3], Computational Sustainability[4], Research Methodology[5], and several scientific articles, and internet-based material. Assignments of the exercises follow the lectures and shall provide a basis for further understanding. Moreover, the exercises contain elements of self-reflective training, with the intent to support for approaching mature views on SD, and especially on IT for SD. All is presented in the class and discussed amongst the students and the teacher, which should bring even further values to the matters discussed.

Themes of assignments include:

- Design a digital user interface that should be used to inform the common public about SD.
- Study one of the ICT contributions to the 17 SDGs, from *'Fast-forward_progress_report_414709 FINAL.pdf'*, present it to the co-students, and initiate discussions.
- Study articles on ethical aspects, for instance, with respect to the AI revolution coming fast. Present and discuss in class.

Self-reflective training was conducted iteratively during the exercises and were structured around a quite large number of statements, that the students should reflect on individually, and then discuss in class. The individual reflections mostly were summarized in written forms, but also mentimeter-based systems[6] was used. Example of statements follow:

- I think the chosen set of the SDGs is a good representation of how we shall approach sustainable development.
- Computer Science and Software Engineering is absolutely necessary to approach the SDGs.
- The UN is the best-suited organization to be responsible for global issues.
- In my home country, I feel that there is an awareness of the importance of sustainability at large!
- At a personal level, I live a sustainable life.
- Water is clearly the most important sustainability issue.
- IT-based systems could clearly contribute to waste-management, a clean city, and a clean environment.
- All the SDGs are clearly interconnected.

[3] Hedenus, Fredrik, Persson, Martin & Sprei, Frances (2018), Sustainable Development – Nuances and Perspectives. 1 edition. Lund: Studentlitteratur (140 p).
[4] Lässig, Jörg, Kersting, Kristian & Morik, Katharina (Eds.) (2016), Computational Sustainability (Studies in Computational Intelligence Volume 645). Cham: Springer International Publishing (276 p).
[5] Oates, Briony J (2006), Researching Information Systems and Computing. London: Sage Publications (360 p).
[6] Engage your audience & eliminate awkward silences, https://www.mentimeter.com/

- Self-reflection tests like this clearly contributes to higher levels of maturity when approaching projects with sustainability themes.

It was made clear from the teacher that the students should feel free in their approach to the statements, and not give answers that they think the teacher expected.

Finally, the course focused on a design project, where the main theme for the project was decided upon by the teacher, that is, SDG 11, on *Sustainable Cities*. The choice of that SGD was based upon the inherent complexity of that SDG and that it may be dependent on further SDGs. Still, it was up to the students to take further focus initiatives within the frames of *Sustainable Cities*. A demand was that the students should come up with IT-solutions to an observed problem and design an IT-based architecture that solves the problem. A report shall conclude the project, with a presentation within the class.

2.2 Project in Multidisciplinary Contexts

The course[7] is focused on a main aim of '*design and implementation of projects in multidisciplinary contexts and concepts and techniques for implementing projects in research contexts*.' To meet that aim, student projects have been grounded in applied research projects involving researchers at CS@HKR, where contributions can be seen in contexts of SD. Examples of such research projects include:

1. *Identifying bacteria in drinking water*. The project has involved Microbiology researchers at Lund University[8], as well as representatives of the Ringsjöverket Drinking Water Treatment Plant[9]. The project clearly connects to SDG 6, on *Clean Water*.
2. *Identifying cancer cells in blood samples*. The project was guested by researchers in Bioanalysis at HKR. The project connects to SDG 3, on *Good Health and Well Being*.
3. *Identifying cases of cracks in concrete of bridge fundaments*. The project was connected to Öresundsbrokonsortiet[10], that manages the bridge between Sweden and Denmark, and relates to SDG 11, on *Sustainable Cities* (there is no *Sustainable Regions* amongst the SDGs).
4. *Analyzing movements of mallards in local areas*. The project has been guested by researchers in Environmental Science at HKR, and relates especially to SDG 15, *life on land*.

The projects, that are chosen by the teachers, are conducted through iterative project meetings, where students are guided further through the process of fulfilling their projects. The course ends up with a final presentation by the students, and a final written report. To solve the project problems, the students need to apply techniques

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[7] Project in Multidisciplinary Contexts - 9 credits, https://www.hkr.se/en/course/DT586D/course-syllabus

[8] Lund University research Magazine, http://www.researchmagazine.lu.se/2016/02/17/our-drinking-water-pipes-are-teeming-with-bacteria/

[9] Sydvatten – collaborating for public welfare, https://sydvatten.se/app/uploads/2023/04/Verksprocessr_eng_fo%CC%88r-hemsidan_2023.pdf

[10] Øresundsbro Konsortiet, https://www.oresundsbron.com/en/about-oresundsbron/about-us/oresundsbro-konsortiet

of courses learnt at the previous semester. Thus, the course lives up to aims for SD, Computer Science research themes, as well as multi-disciplinarity.

3 RESULTS

A program evaluation was conducted by representatives of CS@HKR in 2021, to get an overview insight in students' attitudes towards the program. On a five graded scale, students responded to statements regarding different aspects of the program, where 5 corresponds to the most positive attitude, and 1 to the least. Overall, the students responded very positively, with a mean value over all students and statements of 4.75. A 5 was given to statements, such as, '*The programme syllabus has corresponded well to the actual content of the program'*, '*I have acquired insights about research in many subjects that were covered in the courses'*, and '*Communication with the teachers has worked well in general'*. The lowest value, 4.25 was given to '*I feel that the program content and structure give me good opportunities to get jobs in the IT-sector (programming, consulting, development etc.)'.*

Moreover, all university programs shall be evaluated in regulated ways, including this master program. In 2022 an evaluation of the program was conducted by HKR-internal, as well as external evaluators, from academia and industry. That evaluation concerned both organizational and program-structural aspects and showed a general satisfaction with the program. Criticism and potentials, pointed out though, concerned more industrial contacts with the region's industry, and a strive after a second master year. The most critical point regarded how to attract larger groups of students. The program has suffered from small groups of attending students. Very few of the students at the department's bachelor level show interest in continuing at the master level, the students of the program are mostly attracted internationally.

To meet the criticism regarding contacts with the region's industry, representatives from such contexts will be invited for guest lecturing. It is here considered valuable that such lectures not only present technical aspects of interest, but that those also should have interesting points of connection to the study program with respect to contexts such as SD or the Fourth Industrial Revolution. What was possibly not highlighted during the evaluation was that several of the degree projects were actually done against companies. This also creates opportunities for the students to be employed after graduation, and for the international students to remain in Sweden, which several of them seem to want.

To meet the critical matter of low student enrollment, a more offensive, but still gentle, strategy has been introduced. Applying students have been contacted, and will be contacted continuously, and provided with information regarding the study program, how to live and act in Sweden, and more. The students will be treated as if they already have accepted to take part of the program. Of course, they still have their own free will in their final decisions.

At levels of courses, course evaluations have shown satisfactory results, with the latest mean values provided by students (same scale used as pointed out above), autumn 2022 of 4.4 for the 'methods-course', and spring 2023, of 4.3 for the 'projects-course'. Qualitative judgements include:

- The Methods-course:
    - *I learned a lot from this class. This class allowed me to systematically understand the relationship between sustainable development and computer science, and also exercised my reading and writing skills.*
    - *It is good to know how the computer science is contributing for sustainable goals to make the world a better place to live and the way think to achieve the sustainable goals 2030 is quite motivating and challenging too*.
- The Project-course:
    - *Through this course, I learned how to work in small groups to complete a project. And the projects that this course focuses on are also very interesting. Not only did I learn about technologies such as data processing and machine learning, but also the living habits of some species of ducks, etc., which are very in line with the topic of sustainable development.*
    - *The project meeting we had with guests in middle of the course with guests from environmental department and some faculty from science department it would have been better we have at initial stage*

Getting back to the self-reflecting training of the exercises, as mentioned in previous section, a more comprehensive study on this has previously been made by the author of this contribution and presented at a faculty meeting. It is outside the scope of this paper to dig more in the details, but what is interesting is that students mostly have been positive towards this kind of exercise, which is also shown through positive responses towards the statement '*Self-reflection tests like this clearly contributes to higher levels of maturity when approaching projects with sustainability themes*.'.

An interesting question concerns what happens next with the students. While [8] in first place is addressing how to prepare the university's educators towards effective teaching regarding SD, that report also points out a need for investigating what happens with the students after their education. That is, how do they contribute to future society with respect to SD? Currently it is well known that the students are highly employable, some even continue their careers in academia. Still, the explicit information on the impact by the alumni on SD is rather vague, and as pointed out by [8], clarifying on this is a both interesting and important potential future work.

4 SUMMARY

To sum up: the author of this paper was initially engaged when the SDSN NE was launched and saw an interest in contributions from the field of computer science to approach the SDGs of the UN's Agenda 2030. Furthermore, the author was engaged in investigating proposals on how to meet the criticism towards the home university's lack of ways to manage SD at different levels. One of the proposals addressed a course for educators to guide them in teaching-learning for SD. The involvement in the creation of such a course provided a piece of the puzzle to complete the design and implementation of the revision of a master's program. In that program, computer science students are given the potential to contribute as future agents of positive change.

This paper has reported that the program works well, both at program level and in the courses presented. The students have generally shown interest and satisfaction both in relation to computer science and SD.

In program evaluations, it has been suggested that further work towards industrial contacts is seen as valuable for the program, as well as a striving towards a two-year master programme. A critical problem that the current program has, though, is the low number of attending students, which has caused the program to be questioned and in need of further revisions.

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USING SYSTEMS THINKING TO DESIGN EDUCATION TO MAKE A DIFFERENCE – A PROGRESS REPORT

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ABSTRACT

The Birmingham Centre for Rail Research and Education (BCRRE) delivers research and education to benefit the international rail industry, including an MSc programme which is designed to equip students with the skills needed to lead multidisciplinary engineering projects. The authors are trying to apply some of the systems thinking taught in the programme to the programme itself. It is established practice to maintain learning outcomes for an educational programme and we do that, but we describe how we are trying to improve the information available to us about what the industry wants and the varying needs of our student population. Our information-gathering processes are not just passive feedback loops but are actively focussed on areas of interest. We are also using the V diagram (a systems engineering concept) as a framework for maintaining line of sight to the full set of

feedback information in order to assemble a richer picture to support more balanced decision-making. We describe how our approach is already producing richer input which we are using to improve our programme and why we are encouraged that our approach can make a positive difference to achieve a better educational experience in engineering disciplines.

1 INTRODUCTION

In this paper we describe our experience of applying some aspects of systems thinking to an MSc programme.

1.1 The Railway Systems Engineering and Integration MSc programme

The Birmingham Centre for Rail Research and Education (BCRRE) delivers education and carries out research that is intended to benefit the rail sector in the UK and worldwide. All three authors work at this institution where we are involved in the delivery of education as well as research into issues related to the delivery of education.

Railways are very interconnected systems. The trains, the track, the signalling, the stations, the timetable and many other things all work tightly together such that changing one part can very easily upset another. The different parts of the railway are looked after by different disciplines. As a consequence, in order to successfully deliver a project that will change the railway, it is necessary to manage the interfaces between the parts of the railway and co-ordinate the disciplines.

In other sectors, such as defence and aerospace, there has been, for more than half a century, a specialist discipline concerned with this management and co-ordination called ‘systems engineering’ (SE). As modern technology drives an increase in complexity and interconnectivity in railways, railways are increasingly coming to realise that they need to adopt the principles of SE in order to avoid expensive mistakes.

BCRRE’s educational offerings include an MSc programme in ‘Railway Systems Engineering and Integration’ (RSEI) on which students obtain a grounding in SE.

1.2 Systems engineering and systems thinking

SE involves obtaining a clear and accurate understanding of what is wanted from a system and then systematically focussing design, implementation and testing on delivering that.

The approach is often illustrated as a ‘V diagram’ and fig. 1 indicates how this might look for a project to replace some railway signalling. In the figure, time runs from left to right and the vertical dimension indicates ‘granularity’ with activities relating to the whole system at the top and activities related to parts of the system at the bottom.

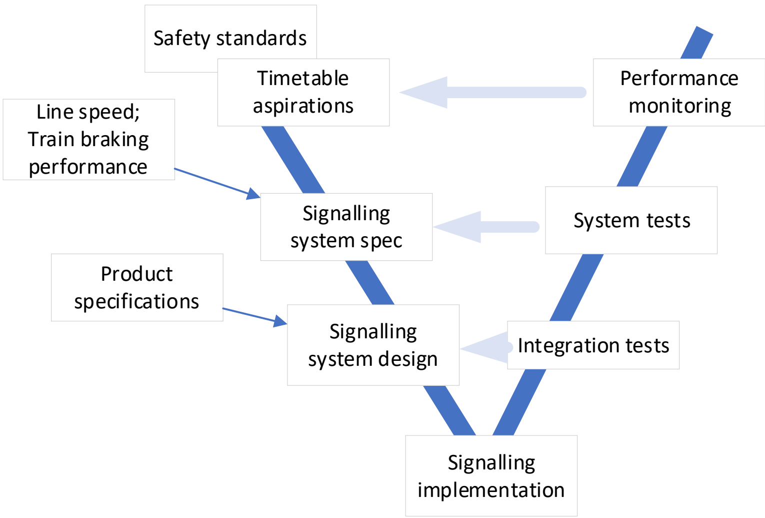

Fig. 1. A simplified V diagram for a signalling project

The activities on the left-hand side of the ‘V’ cover specification of the system and its components followed by design and implementation of the components. The activities on the right-hand side of the ‘V’ cover putting the components to work together and checking out the components and the system.

No system exists in a vacuum and the thin arrows coming in from the left indicate facts about the real world which need to be taken into account, if the system is to be successful.

If sufficient records are kept of the process, anyone designing or testing part of the system can establish how their work contributes to the overall objectives. One sometimes says that there is ‘line of sight’ to the objectives. Then, if the objectives or context, or our understanding of these things, should change, the V diagram provides a framework for efficiently and effectively changing the system in response.

In this paper the authors will explore how the V diagram and some of the ideas behind it might be used as a framework for efficiently and effectively changing the RSEI MSc programme rather than a technical railway system.

2 CURRENT PRACTICE

There has been a growing understanding of the importance of systems thinking as a requirement for successful engineers (McNaughton 2022) and the teaching of engineering has been moving away from reductionism and toward a more holistic perspective, with a need for engineers to have a broader knowledge of areas associated to their own and their interrelated systems. Thought has been given to teaching systems thinking both within engineering and other disciplines (Ravi et al. 2021) however the authors have found little consideration of how systems thinking could be used to improve teaching practice. If one accepts that systems thinking is an important skill for the engineer to develop, then thought also needs to be given to how a learning environment should be planned in order to facilitate its learning.

Of course, the principles underpinning the V diagram have already been partially adopted in further education. It is normal practice (Barkley and Major 2022) to define learning outcomes for an educational programme and then design the programme to meet these outcomes. Learning outcomes are based on what the learning institution and relevant advising bodies believe learners need to know. However, before embarking on or funding a period of education, students and their employers will normally have personal and business learning outcomes they hope to achieve. Successful programmes will be well aligned with these real needs.

In SE, one attempt to align industry needs with academic offerings has been 'The Graduate Reference Curriculum for Systems Engineering' (Pyster et al. 2012), a collaborative project designed to provide guidance on what providers of SE education should teach. It includes a V diagram with 'Program Objectives' at the top left. These adaptable objectives are focussed on student capability and employability. Similarly, Van Peppen and van der Ploeg (2000) established industry and learner objectives for a four-year master's programme in systems analysis, policy and analysis. In the UK, the Engineering Council publishes required learning outcomes for the Accreditation of Higher Education Programmes in engineering (Engineering Council 2020). These are frequently updated as the engineering industry undergoes change, such as changes in technologies. However, each of these documents, by necessity, serve multiple sectors with varying needs.

Some of our students take the MSc programme as part of the UK Rail and Rail Systems Principal Engineer degree apprenticeship. The standard for this apprenticeship (Institute for Apprenticeship and Technical Education 2018), which was written in consultation with the rail industry, specifies criteria for knowledge. skills and behaviours that an apprentice should have or exhibit upon successful completion of their apprenticeship. These criteria are about to undergo their first review, and with feedback from industry, it may be possible to identify the business benefits associated with meeting them.

However, although each of these sources provide elements for consideration, they sometimes contradict each other, and none provides a comprehensive and traceable set of business outcomes that are specific to our programme.

3 OUR APPROACH

As the authors have acknowledged, it is established practice to follow the constructive model, that is, to design educational material against defined learning outcomes and an understanding of what potential students want and then to assess whether these outcomes have been achieved. This could be represented as an application of the V diagram as illustrated in the boxes with a white background in fig. 2.

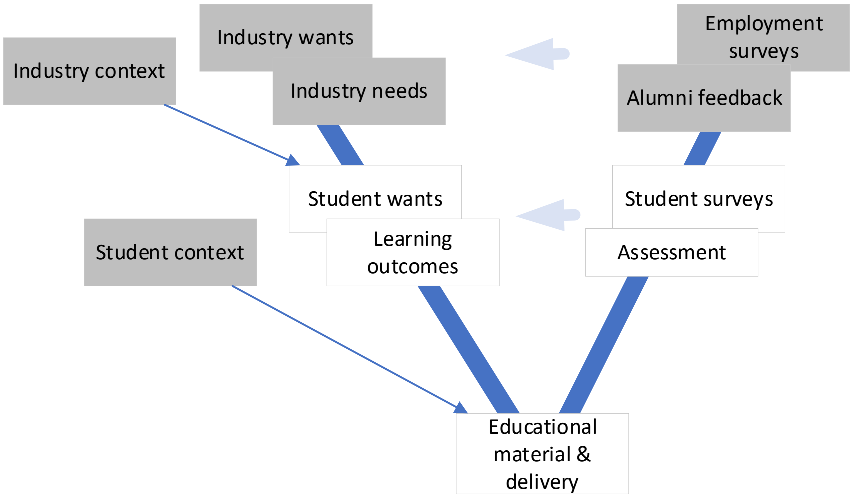

Fig.2. Current and extended practice in creating and improving an educational programme

We apply this process to the improvement of the RSEI programme, but our standard feedback arrangements provide us with feedback that is incomplete, potentially biased and occasionally conflicting. We are trying to improve the information available to us by extending it into the areas shown in grey. Our information gathering processes are not just passive feedback loops but are actively focussed on areas of interest. We are also using the V diagram as a framework for maintaining line of sight to the full set of feedback information in order to assemble a richer picture to support more balanced decision making.

4 KEEPING OUR UNDERSTANDING OF INDUSTRY WANTS AND NEEDS UP-TO-DATE

To contribute to industrial success, providers of relevant education need to help close 'skill gaps' - mismatches between the skills of available workers and the skills needs of employers (Department for Science 2021).

The RSEI MSc programme is designed to narrow the skills gap in the area of railway engineering. To understand this gap better the authors are carrying out research into the skill needs in this area in three different countries: the UK, the United Arab Emirates and Tanzania. To collect the skill expectations in these different cases, we are conducting online surveys and semi-structured interviews. We already convene a UK industry advisory board to collect industry feedback on the programme. We hope that these surveys and interviews will complement the industry advisory board by moving the discussion from the programme to the needs of industry and doing so for industry worldwide.

Only the literature review has been completed at the current stage. The literature review about the rail industry, its future, and railway education and training, shows that the skill expectations can mainly be classified in two categories: technical skills and soft skills. For the technical skills, the main gaps appear to be developing a holistic view of railway engineering and putting theoretical/technological knowledge into practice look like the main skill expectations from the industrial side. For the soft skills, the main gaps appear to be management and communication skills.

These findings are corroborated by other research into rail skills and skill expectations, most of which is of European origin. According to the European based research on skills education and training for the rail industry (European Union SKILLRAIL, SKILLFUL, and ASTONRAIL projects) (SKILLRAIL 2012), and UK Industrial Strategy – Rail Sector Skills Delivery Plan (GOV.UK 2018), there are also two main components of the skills gap in rail:

- Management and leadership skills.
- Being able to take account of new technologies and develop appropriate standards.

The RSEI MSc does cover management and leadership skills as well as innovation but, even though the findings of our ongoing research are very preliminary, the fact that these topics arise from multiple research activities is encouraging us to look again at them to see whether we should strengthen our teaching in these areas.

5 IMPROVING OUR UNDERSTANDING OF STUDENT CONTEXT AND WANTS

Students attending the RSEI MSc programme generally have rail industry experience. They will normally have specialised in one area of the rail industry and will be attending the programme to gain a wider knowledge of the industry as a whole. Around half of the cohort are students from the UK rail industry who by the end of the programme aim to have achieved promotion and/or engineering chartership. The rest of the cohort are international students, some of whom on completing the programme intend to return to home countries to further their careers, while others are looking for careers in the UK rail industry.

We also see students with a variety of educational backgrounds, including UK degrees, alternative qualifications such as a Higher National Diploma and overseas qualifications.

Therefore, we understand that our student cohort will have different wants, but also different needs in terms of support for them to achieve their learning goals. To be able to develop the programme and improve the support given, we need to have a better understanding of the students, and to obtain data on the optimum way to provide that support. It is worth considering that feedback obtained from students in a higher education setting can be prone to bias (Richardson 2005). This includes feedback collected from satisfaction surveys or other methods based on student opinion. Although, through surveys, anonymous data from large groups can be collected in a way that can be quantified, often this data lacks context which makes it difficult to interpret in terms of feedback for improvement (Desimone & Le Floch, 2004).

Other information such as the constant feedback loop between students and educators which comes from observing students' behaviour, questions, requests for help or even body language, can also be difficult to interpret. A few dominant students can give a skewed view and mean the view of the many is ignored, or data can be difficult to interpret in a non-biased way. Therefore, we need to look for methods of data collection, both quantitative and qualitative which remove subjective bias, and we need to consider how to use a number of different data collection methods to support findings.

Examining attainment results achieved in assessments across the taught modules within the program, has allowed us to identify areas where there are differences between certain groups of students and where support may be needed. In the rail program one obvious difference in attainment was between home and international students, with the most recent results demonstrating home students achieving 8% higher on average across the modules. When looking at data across several years, this gap appears to be growing. Our previous assumption that work experience in rail would give students an advantage in the program, was not supported by the data. English as a first language also appeared to have little effect on results. The largest single indicator of low results appeared to be that previous academic study had been undertaken overseas.

To understand why this gap is occurring, a study was undertaken to look at assignments in one module containing 56 students, of which 29 were international and 27 home students. Although, there were certain errors that were common to all students, by examining the written assignments it was possible to identify areas where each group needed support. For international students support was needed with understanding how UK academic questions are phrased and how to start answering them. Describing evidence for arguments and demonstrating critical thinking skills were also areas which needed support. Comparison between home and international students in the examination demonstrated that international students tended to achieve a higher percentage of marks from mathematics questions than home students which again helps to target support.

More detailed data focused on programme improvements has been collected through interviews with students. Issues such as the need for assistance with vocabulary and the use of recorded teaching materials for support have already been acted on. However, perhaps more interesting was the way in which interview responses could disagree strongly with other findings. Some such as interviewees claims that they watch recordings of lectures are easy to check using our software analytics, while insistences that there is little difference between assessment undertaken in home countries and in the UK are not backed by the attainment evidence or that obtained by the detailed study of assignment responses.

Finally, feedback has been obtained through semi-structured observations of group interactions. Although a powerful tool, little research has involved classroom observation (Agostinelli, 2021) and there is little consensus on how observation should be carried out. In this case observations took place over a period of ten hours during a week of group tasks. The aim was to record interactions between students and to look for patterns in behaviour, such as which students were more likely to be taking leadership roles, who was dominating speaking and who did what. In general, observations appeared to support findings from other studies. International students were more likely not to attend the group sessions, were less likely to speak in the group setting and appeared to complete a smaller percentage of the task, all issues which may lead to lower attainment in assignments at a later stage. Students were not directly questioned during the observation, however, several students wanted to talk about their experiences of group work which led to some interesting contrasts between what was observed and the perceptions of the students. For example, some home students were confident that they had tried to elicit discussion from international students, when observation suggested little contact. Also, a home student with industrial experience who had been observed to act as group leader and to organise other students, was convinced that they had undertaken no such role. One can observe what happens, but not what is in the mind of the student which demonstrates the need for multiple feedback loops.

This data that we have collected is already being used to inform changes in the coming year, with materials being developed for our Primer module to help students engage more effectively with assignments.

6 CONCLUSIONS

We have described how we are using the V diagram as a framework for improving the feedback available to us in order to inform improvements to the RSEI programme. We have sketched our research that we are carrying out into:

- what industry wants and needs from the type of education that we offer; and
- the variation in our student population and how we can take this into account to produce more consistent outcomes.

Our research is continuing but then so is the process of improving our MSc. We are committed to gradual but continuing improvement and, while we do not have definitive results yet, our interim findings are already providing us with richer input into the decisions that we are taking to improve our programme. Importantly, the results of our research are challenging some of our preconceptions which is an indication that our understanding is improved.

We are also using the V diagram as a framework for maintaining line of sight to the full set of feedback information in order to assemble a consolidated picture. Doing this brings into focus the conflicts between sources of feedback. Reconciling conflicting input is an unavoidable aspect of continual improvement. With richer input and the ‘line of sight’ afforded by the V diagram approach, we are confident that we can make better and more balanced decisions. Better and more balanced decisions should lead to a programme that is better aligned with the needs and wants of industry and students and the elimination of the effort required to undo undesirable changes.

We will complete our initial avenues of research, but we are already benefiting from the interim results and our research encourages that, if applied carefully, the ideas of SE can make a positive difference to achieve a better educational experience in engineering disciplines.

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MEASURING EFFECTS OF VIDEO LECTURES ON IMPROVING STUDENT ENGAGEMENT AND OUTCOMES

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Conference Key Areas: *Innovative Teaching and Learning Methods, Virtual and Remote Education in a Post Covid-19 World*

Keywords: *Video Integration, Lesson Activities, Improvement Grades, Post-Pandemic Education, Digital Education, Mathematics Master Course*

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ABSTRACT

In the current age, digital advancements have shaped the educational landscape by providing numerous possibilities for a fast and on-demand influx of information for students. This brings an additional difficulty for course designers in how to incorporate such technologies in teaching in an optimal way. Key examples are educational videos, which are especially relevant now due to the increase in accessibility of pre-made videos and recording technology since the pandemic. This puts post-pandemic teaching in the new but revolutionary position to complement in-person teaching with videos.

In this study, we examine the effect of videos combined with in-person teaching in a mathematics master course in motivation and grades. This experiment is specifically insightful due to our course consisting of three different topics (A,B,C). In Year 1 (control group), the course was taught traditionally. In Year 2 (experimental group), we provided additional video lectures on (A), while keeping (B) and (C) as before. We compare assessment and survey results between and within years.

Videos did not increase the students' motivation for the topic (Fisher exact test p = 0.06182). The intervention did not improve the midterm or final exam grades on (A) between years. Students who watched videos did not score significantly better on their assignments (2MWUt p = 0.275) nor on their exams (2MWUt p = 0.745) than students who did not watch the videos. However, a positive effect size was observed between years, while the intervention led to a negative effect size within the same year.

1 INTRODUCTION

Technology is fully integrated into everyday life, which has had a positive effect on students' internet and computer skills and their attitude towards digital educational resources from a young age (Kuhlemeier and Hemker 2007) and (Sharples et al. 2007). This presents an opportunity in transferring this experience in a classroom environment. Specifically for learning mathematics at university, using *online videos* has been shown to have advantages. The topic of video integration into in-person lectures is especially relevant in a post-pandemic teaching environment, where copious amounts of video material and recording hardware, used during the pandemic, are available. Teaching staff both acknowledges the importance of in-person teaching and recognises the benefits of videos and recordings (Robson, Gardner, Dommett 2022). It is therefore of great interest to investigate if the combination of in-person teaching and video material can elevate teaching in a post-pandemic time.

Benefits of videos include flexibility of scheduling and pace, and avoidance of long lectures. In contrast, the main perceived advantages of lectures are the ability to engage in group tasks, to ask questions, and to learn 'gradually' (Howard, Meehan, Parnell 2018). The same study also shows that students in clusters with high lecture attendance achieve, on average, higher marks in the module. Therefore, videos provide a useful resource, which should be used in this context only and in conjunction with lectures. Further studies focus on the relationship between learning and time spent on lectures and/or videos. Findings show that students use videos as either a complement to or substitute for the lecture, and time spent using either or both resources has a significant impact on learning (Meehan and McCallig 2019).

In this work, we measure the effect of video-integrated education in combination with in-person teaching. The goal of this work is to answer the following questions:

1. Does the addition of videos to in-person teaching improve the students' grades?
2. Does the addition of videos to in-person teaching improve the students' engagement with the course?

In order to give a statistically sound answer to these questions, we track the data of two years of the same master course in mathematics at the Eindhoven University of Technology in the Netherlands. In the first year, the course was given traditionally, while in the following year videos were included. The first year serves as a benchmarking iteration where typical course standards are maintained. This is followed by an experimental iteration in the following year where, in addition to the standard practice of the course, video lectures are *partly* provided, i.e. *only* for a specific part of the course. This creates two natural control groups. Within a year, it allows us to compare the effect of the videos by comparing grades between the topic where videos were provided for or not; between years, grades on the other topics help check for heterogeneity. We refer to Section 2.1 for a detailed overview of the experimental setup.

We use the answers to the questions above to formulate concrete advice if additional videos have an inherent added value to in-person teaching for students. Based on this advice, one may include videos in their course if the expected benefits justify the investment of time and resources. Note that these conclusions are in the specific context of a specialized and rather challenging first year master course in mathematics.

2 METHODOLOGY

2.1 Experimental setup

The experiment takes place in an established master course in mathematics in the Netherlands. The course comprises three topics in stochastics: renewal processes (A), branching processes (B), and Brownian motion (C), which are taught sequentially in three modules in this order. The three topics are sufficiently independent; i.e. for any module there are no required prerequisites from a previous module. Throughout the course, basic probability topics (D) appear as needed. The design involves a two-hour, on-campus lecture, followed by a two-hour guided self-study, twice per week for eight weeks. Examination weeks are scheduled afterwards. The material offered to students is lecture notes, one single book covering all topics, instruction sets, sketches of solutions to the instruction exercises, and practice exam sets for the final examination.

To assess students, at the end of each module a midterm examination is given in the form of take-home problems that can be solved in pairs or alone. At the end of the course, students take a three-hour individual final exam where all topics are tested. The midterms and the final exam are graded on a 0–10 scale. The three midterms count each for 10% of the final grade and the final exam counts for 70% of the final grade. A final grade of at least 5.50 is needed to pass the course.

The course was taught with the same setup, teaching staff, and material (with the exception being the inclusion of the videos required to perform this experiment) between two years. In Year 1, the course was given traditionally, i.e. with the setup described above. In Year 2, videos were recorded by the lecturer on (A) and offered to all students at the beginning of the course. Students could optionally engage with the videos throughout the whole course and examination period, i.e. for a total of 10 weeks.

The videos used in Year 2 consisted of six mini-lectures: three informative presentations on theoretical topics and three on applications. For both parts, one video was in the scope of (A) and handled in class and two were new material. The videos were put online and it was indicated if a video was on theory or on an application. The differentiation between theory and applications as well as known and new subjects could have allowed for a determination of whether students are seeking help when engaging with a video or are intrinsically interested to learn more about (A). However, this differentiation, together with the fact that the material was optional, reduced the relevant sample size per video, thus not allowing for meaningful statistical analysis.

By providing videos only for one out of three topics, a meaningful comparison can be made between the performance of the students in two consecutive years on the topics with and without videos. Students were offered the new video material but were not obliged to follow it. All students were asked in a questionnaire if they engaged with the videos or not. This allowed for additional comparisons within (A) in Year 2.

While Year 2 took place during the Covid-19 pandemic, this specific course was chosen by the Programme Director for on-campus education allowing for a fair comparison between the two years. In addition to keeping all setup, material, and staff identical, care was taken to avoid confounding factors by design. For example, each midterm per topic and each topic in the final exam was assessed by the same person both years. The number of registered students was 73 and 74 in the two years.

2.2 Data and reliability

We use anonymised data of students of Years 1 and 2 contained in three datasets. Dataset 1 consists of midterm grades of (A,B,C) and exam grades per topic (A,B,C,D) and year. The grades on (A) between years may attest for the effect of videos, while the grades on (B,C,D) give an indication of difference between the two years as no changes in education were made for these topics, thereby assessing the effect of possible confounding factors due to the different cohorts.

To perform statistical tests based on Dataset 1, we ensure that student groups from Years 1 and 2 are independent. Therefore, we remove students that were present in both years to avoid dependencies. For a fair comparison, we also remove students in Year 1 if they had taken the course the previous year, as they had prior knowledge. However, this introduces a bias toward higher grades in Year 1 and therefore students that scored lower than a 5 on their exams in Year 2 are removed as well. Therefore, the data is limited to the groups of students from either year that took the course for the first time *and* passed, making these groups comparable and independent. The resulting sample sizes in each year are again similar: 45 and 42 students.

As is usual with test or survey data, we test the reliability of the midterm, exam, and survey questions in order to identify and remove questions that are not discriminatory. In Dataset 1, we measure the overall reliability of the midterm and final exam with the Cronbach alpha coefficient (Cronbach 1951). We then look at the average score of each question and its correlation with the other questions in the exam. If the correlation of the total score on the question is below 0.15 or above 0.85 or the correlation with the other questions is below 0.15, the question is removed from the analysis. Data per question was not available for the midterm on (B) and (C) in Year 1 and thus all questions of these midterms are included in the analysis.

Dataset 2 consists of survey results of students (on a voluntary basis) in Year 2. The first part of the survey consisted of basic questions: which of the six video lectures (if any) did they watch; which was their favourite; what was the number of hours they spent on the course per module. The latter information is used to investigate if students that watched at least one video are statistically different than those who did not watch the videos (e.g., harder or less hard working). This is a key measure to account for the possible occurrence of *selection bias*, since watching the videos was voluntary. Surveys were performed at the end of each module rather than only at the end of the course, thus allowing students to have a fresh (and hopefully accurate) estimation of the effort they expended. The second part of the survey asked students two main questions on what the effect of the videos was for them:

1. If it made (A) more interesting for them;
2. If it made the course as a whole more interesting for them.

On each question the students could respond with “yes”, “somewhat” and “no”. This information is used to test the motivation for (A) and for the course as a whole of students between those that watched at least one video and those who did not.

Dataset 3 consists of Student Evaluation of Teaching (SET) reports for the two years. They were used to test whether students in Year 2 spent more time learning.

2.3 Statistical methods

To answer the first main question on whether the video lectures had an effect on grades, we examine the following hypotheses:

H_0: The probability of a uniformly sampled grade from Year 1 being larger / smaller than a uniformly sampled grade from Year 2 is ½.
H_1: The probability of a uniformly sampled grade from Year 1 being larger / smaller than a uniformly sampled grade from Year 2 is not ½.

For this, we use the grades in Years 1 and 2 (Dataset 1) and employ the two-sided Mann-Witney U test (2MWU) (Mann and Whitney 1947). This non-parametric test investigates the locations of two independent samples by using ranks and is suitable for small-sample ordinal data, as is the case when examining grades. We also report the median and interquartile range (IQR) of the grades of the two years separately.

To answer the second main question on whether the video lectures had an effect on the engagement of students with the course, after testing for differences in engagement between years, we examine the following hypotheses:

H_0: The results between groups in Year 2 are from the same distribution.
H_1: The results between groups in Year 2 are not from the same distribution.

For the comparison of survey results within Year 2 (Dataset 2), we use the Fisher’s exact test (Sprent 2011). It is suitable for categorical survey data, as we have, where students can answer either “yes”, “somewhat”, or “no”, from independent groups of students that did not watch the videos and the group of students that watched at least one video. The statistical tests are performed on a significance level of $\alpha = 0.05$ that is adjusted to correct for multiple testing where needed: when the final exam is considered both as a whole, and as a set of subparts comprising the topics (Bonferroni correction, $\alpha = 0.025$). We do not correct for multiple testing when considering midterms and the final on the same topic as we believe they can be seen as independent due to the different modalities (take-home/in-class, group/individual, with/without resources).

In all relevant cases, in addition to statistical significance, we also report the effect sizes. Unless the impact of the intervention is huge, a study of this size is unlikely to get a statistically significant result. Thus, reporting the effect adds nuance to the results. The effect size is a standardized, scale-free measure of the relative size of the effect of an intervention. It is particularly useful for quantifying effects measured on arbitrary scales. In education, if it could be shown that making a small and inexpensive change would raise academic achievement by an effect size of even as little as 0.1, then this could be a very significant improvement, particularly if the improvement applied uniformly to all students, and even more so if the effect were cumulative over time; see also (Coe 2002) for a discussion.

3 RESULTS

3.1 Between years

The analysis of the SET results between years shows that students spent on average the same amount of time on the graded component of each module, with means 8.2915 hours in Year 1 and 8.2995 hours in Year 2 for module (A), and on the whole course.

Dataset 3 is gathered by the university and reported on an aggregate level. We thus cannot distinguish between students who repeated the course and those who did not.

In Table 1, we compare the grades of Year 1 to the grades of Year 2 in Dataset 1. For the midterms, we observe a significant difference in grades only for midterm (C), while the other midterm grades did not differ significantly between years. This may indicate that Year 2 had stronger students. This is, however, in strong contrast with final exam grades on (C) and (D), where students scored significantly lower in Year 2. It is notable that the effect of the intervention is positive for all midterms and the intervention topic (A) in the final exam, but negative for all other topics in the final exam.

Table 1: Summary statistics of the grades per topic for the midterms (A,B,C) and final exams (A,B,C,D) in Years 1 and 2. Non-discriminatory questions were removed when possible. The p-value corresponds to the 2MWU test between Years 1 and 2. Boldfaced values indicate that the null hypothesis was rejected under a significance level $\alpha = 0.05$ (0.025 where a correction for multiple testing was needed). The Cliff's Delta effect size and 95% confidence interval are given.*

Between years	**Year 1 (control)**			**Year 2 (intervention)**			**p-value**	**Effect size**	**95% CI of the effect size**
	n	**Median**	**IQR**	**n**	**Median**	**IQR**			
Midterm (A)	30	8.15	[7.18,8.88]	27	8.45	[7.70,9.50]	0.149	0.217	[-0.087,0.483]
Midterm (B)	30	9.00	[8.00,9.75]	27	9.10	[8.80,9.40]	0.445	0.118	[-0.199,0.412]
Midterm (C)	30	7.50	[7.00,8.50]	27	8.70	[8.06,9.71]	**<0.001**	**0.546**	[0.260,0.744]
Final (A)	45	4.00	[1.00,7.00]	42	5.38	[4.75,6.25]	0.033*	0.265	[0.003,0.493]
Final (B)	45	7.60	[6.00,9.60]	42	7.5	[6.56,8.30]	0.520*	-0.080	[-0.318,0.167]
Final (C)	45	8.67	[6.89,9.78]	42	7.29	[6.82,8.61]	**0.007***	**-0.338**	[-0.522,-0.123]
Final (D)	45	5.00	[3.33,7.33]	42	3.33	[2.08,4.33]	**0.011***	**-0.318**	[-0.524,-0.076]
Final total	45	7.02	[6.21,7.84]	42	6.61	[5.45,7.19]	0.082*	-0.217	[-0.430,0.018]

3.2 Within Year 2

Next, we compare students within Year 2, separated in two groups: students who watched at least one video and those who did not watch any videos. We examine the results on the two main questions of the survey. The results are presented in Tables 2 and 3. To test whether the number of students reporting an increased motivation for (A), we perform a Fisher exact test. There is not enough evidence to reject the null hypothesis of equal distribution (p-value = 0.06182). To analyse whether videos increased motivation of the course as a whole, we perform the same test on the frequencies reported in Table 3. The outcomes between the two groups differ (p-value = **0.0122**). Thus, we conclude that students feel that videos increased their motivation.

Table 2: Survey results on the question: "Do you feel that the videos made renewal processes more interesting for you? Or in lack of interest, did you appreciate the topic more?"

Increase motivation for (A)	**Yes**	**Somewhat**	**No**	**Total**
Watched a video	5	9	5	19
Did not watch a video	0	4	7	11
Total	5	13	12	30

Table 3: Survey result on the question: "Do you feel that the videos made the course any more interesting? Or do you feel that the videos were of any added value to the course?"

Increase motivation course	**Yes**	**Somewhat**	**No**	**Total**
Watched a video	9	6	4	19
Did not watch a video	0	6	6	12
Total	9	12	10	31

We next consider if students that watched the videos are significantly more engaged with the course. This is tested based on the number of hours students report to have worked on the course per topic. It is important to note that these numbers are self-reported by students. For all samples (i.e. per topic and group) the Shapiro-Wilk test does not reject the hypothesis that the hours reported follow a normal distribution (p-values ranging from 0.092 to 0.925). An F-test does not reject the hypothesis that the samples have the same variance. We thus assume normality of the data and employ a two-sided *t*-test with equal variances to compare the effort in hours between groups. The results are presented in Table 4.

Table 4: Summary statistics of the number of hours students spent studying in total per topic. Students are split into groups that did not watch the videos and that indicated to have watched at least one video. The p-value reported is based on a two-sided t-test with equal variances. The Cohen's d effect size with Hedges g correction is given.

Within Year 2	Did not watch any videos (control)			Watched a video (intervention)			p-value	Effect size	95% CI of the effect size
	n	Mean	S.d.	n	Mean	S.d.			
Topic (A)	27	30.15	12.04	19	37.42	11.90	**0.049**	0.596	[-0.009,1.202]
Topic (B)	27	24.89	11.42	19	27.58	11.49	0.437	0.231	[-0.364,0.826]
Topic (C)	27	25.48	11.47	19	31.26	13.54	0.125	0.460	[-0.141,1.061]
Total	27	80.52	32.07	19	96.26	33.73	0.116	0.472	[-0.129,1.074]

Students who watched a video spent on average more time on (A). The difference in the mean is roughly equal to the time required to watch all videos, which is a possible explanation. All other differences in time spent were not statistically significant.

We also consider if the group that watched the videos scored significantly better on their midterm and final exams. As students were allowed to make their midterms in pairs, we test if the pairs in which *at least one student* watched a video performed better on their midterms than pairs in which *none of the students* watched a video. Additionally, we present the exam grades of students in Year 2 for students that did not watch any of the videos and for students that watched at least one video.

Table 5: Summary statistics of results of student pairs per topic in Year 2. All pairs are clustered into two groups: one in which neither student watched a video and one in which at least one student watched at least one video. We report the p-value of the 2MWU test between groups. Boldfaced values indicate that the null hypothesis is rejected under a significance level $\alpha = 0.05$. (0.025 where a correction for multiple testing is needed). The Cliff's Delta non-parametric effect size and its 95% confidence interval are also given.*

Within Year 2	None watched a video (control)			At least one student watched a video (intervention)			p-value	Effect size	95% CI of the effect size
	n	Median	IQR	n	Median	IQR			
Midterm (A)	11	8.60	[7.78,9.65]	16	7.70	[6.85,8.95]	0.275	-0.325	[-0.683,0.159]
Midterm (B)	11	9.00	[8.73,9.38]	16	9.10	[7.95,9.25]	0.107	-0.149	[-0.524,0.273]
Midterm (C)	11	9.35	[8.39,9.79]	16	8.35	[7.75,8.85]	**0.048**	-0.383	[-0.723,0.106]
Final (A)	22	5.38	[3.91,6.19]	16	5.38	[3.97,6.06]	0.745*	-0.065	[-0.421,0.307]
Final (B)	22	7.40	[5.85,8.23]	16	7.00	[5.88,7.85]	0.679*	-0.082	[-0.430,0.286]
Final (C)	22	7.41	[4.64,8.61]	16	7.09	[6.07,8.39]	0.801*	-0.051	[-0.403,0.313]
Final (D)	22	2.10	[1.00,2.55]	16	1.90	[1.00,2.70]	0.413*	0.045	[-0.331,0.410]
Final total	22	6.12	[4.97,6.58]	16	6.04	[4.71,6.71]	0.859*	-0.028	[-0.389,0.340]

We observe only a significant difference in grades on midterm (C), where the groups that watched the videos scored significantly lower. Therefore, there is no significant change in grades of midterms on (A) or on the exam on (A). Note that in all cases except for topic (D), the effect size of the videos on the grades is negative.

4 CONCLUSION

There no statistically significant improvement in grades between Years 1 and 2. On topic (A) of the final exam, grades seem to be improved, but statistical significance is not reached after Bonferroni correction (p-value=0.033). On the other hand, the effect size is positive (0.265, 95%CI=[0.003, 0.493]). Also on midterm (A), the effect size is positive (0.217, 95%CI=[-0.087, 0.483]), although the result is not statistically significant (p-value=0.149).

As evidenced by the lack of significant unilateral changes in grades for (B,C) between years, we find that one cohort of students was not significantly performing better or worse than the other. Only on the midterm (C), we observed an increase in grades (Y1 7.50 [7.00, 8.50], Y2 8.70 [8.06, 9.71], p-value<0.001), but the results on the final (B,C,D) have negative effect sizes and reach statistical significance for (C,D).

Based on Table 5, we also do not observe a significant difference in grades between students that watched at least one video and students that did not watch any videos within Year 2. This indicates that selection bias did not play a significant effect in the analysis. Also, by the removal of non-discriminatory questions, the most important confounding factors in this analysis have been accounted for. Therefore, we find only a mild marginal effect of videos improving students' grades.

We find some evidence of improvement in motivation in the group of students who watched the videos. Concretely, there is no significant improvement in motivation for (A) based on Table 2 but there is a significant improvement in motivation for the course as a whole based on Table 3.

Moreover, Table 4 shows that students who watched the videos did not engage more in the course in terms of hours spent per topic. As the group that watched at least one video did not significantly work harder for the course than those that did not, according to Table 4, we find that the former group was not engaged with the course more than the latter in terms of hours spent on the course. This outcome shows that the group that chose to watch the videos are not inherently working harder, if measured purely by the amount of time they spend on the course. Therefore, the effect of videos on motivation is marginal, which concludes our second research question. On the other hand, it could be that students already inclined to the subject (and that need to spend less time to grasp the compulsory material), also engage with the videos. However, this is not visible in the grades.

Combining these results implies that the effect of including video material in combination with in-person lectures is modest. Our sample size was limited, especially when considering the complex framework that is analysed and the small effect sizes at hand. This may have prevented us from finding statistically significant results. For similar courses, it is therefore advisable to critically assess if the time and effort for the creation and integration of video is justifiable when the benefits are expected to be limited. On the other hand, the analysis shows no significant negative effect on students' grades or motivation. If videos are readily available and easily to implement, we find no evidence against including them as optional material; however, expectations should be managed accordingly.

5 DISCUSSION

When interpreting the results, it is important to keep in mind that the outcomes are based on two years of a specific master course in mathematics in the Netherlands. Courses of a different level or other university subjects may be better or worse suited for video integration. Additionally, students of different age, level, or field of study may respond differently to videos. The videos were made by the lecturer, with the input of students who took the course in the past years, in order to calibrate the potential interest students may have in the material. Professionally directed videos, or of a different format (in duration or media used), could have a different effect on the engagement of students. Finally, while the course is given in English and open to students from other countries, a large part of the students is Dutch. Different cultures may respond differently to videos.

While we carefully accounted for different confounding factors, it is possible some inevitable and hard to control effects were present on the background. An example is the pandemic that was making its uprise during Year 1, whereas the first pandemic wave was on its decrease during Year 2. Although both years provided on-campus teaching, the pandemic was in very different stages between years. This may have influenced the experiment. For example, students may have been more experienced with video lectures in Year 2 or may have had intrinsic variations in focus and motivation for coursework after the extended measures the pandemic required. As this course was selected for on-campus education, this may have created a welcome respite from isolation, which could be a confounding factor for engagement.

Another potential confounding factor relates to the content of the midterms and exams. They must be distinct between years. We accounted for discrepancies by removing non-discriminatory questions and keeping the graders the same between years. The assessments were designed by the same person. These measures are however not a perfect technique as some differences in level may still be present. Similarly, while the teaching staff did not change between midterms, it is possible that the quality of lectures or grading between years differed. We believe that these effects are mild as Table 1 does not show a convincing consistent difference in results between years.

Future years can expand upon the analysis here. First, the selection bias can be eliminated by making the videos and survey mandatory. However, it is not straightforward how to properly implement this in practice, i.e., how to reward or penalise students who did or did not watch the videos respectively. If future studies increase the sample size of students, it can additionally be tested which type of videos (i.e., on theory or applications) students prefer and if one version typically results in higher grades or motivation. This would add an additional research question to what *kind* of videos are optimal to use.

Future research may also examine the effect of other properties such as video length, quality, and presenter. If future studies allow us to follow students for a longer time, we can test the long-term effects of videos on students. This adds an additional research question if videos improve the *learning retention* of students in practice. While these questions are of great interest, they are left for future investigation.

Overall, our research shows no statistical significant results, but reveals modest effects of this intervention. In closing, it is important to highlight and emphasize the critical significance of not merely assuming the effectiveness of technological interventions in education. Instead, it is crucial to encourage rigorous educational research that enables more thoughtful and informed assessments of similar integrations.

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Problem-Based Learning of Heuristic Methods for Decision Problems in Mathematics, Computer Science and Industrial Engineering

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ABSTRACT

In a digitalized world, most processes can be formalised, measured and described mathematically. The use of analytical methods to optimise such models and decisions constitutes operational research (OR), developing new methods for a specific problem and analysing them are part of discrete optimisation (DO). However, there is limited research on OR and application driven DO in higher education. Furthermore, neither is well integrated into engineering education research.

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In this work, we present a case study of an interdisciplinary Master's course on heuristic methods in the context of OR and DO. We discuss to what extent well-established approaches from engineering education practice, such as Problem-Based Learning, are applicable. Furthermore, we introduce two practical cases and argue that due to its application-oriented nature, OR and DO specifically stimulate independent student work.

Results from evaluations, minute papers and student coursework indicate that the teaching approach successfully contributed to students' achievement of the intended learning outcomes.

To further foster discussion, we not only provide the lecture notes publicly, but also all tutorial and project case data to instructors upon request under a CC BY-NC license.

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1 INTRODUCTION

In a digitalized world, most processes as in logistics, health care, education or production can be formalised, measured and described mathematically. The use of analytical methods to optimise such models and decisions constitutes operational research (OR). Developing new methods for specific problems from these fields and analysing them form a rich source of novel discrete optimisation (DO) problems. This designation is not clear cut: analytics, systems engineering, industrial engineering, operations management, management science, discrete and combinatorial optimisation, algorithms and complexity, and operational (operations) research represent closely linked fields that all deal with the use and development of methods to describe, predict and improve processes.

Many problems can be solved exactly within reasonable time, even for large instances. However, there are also numerous problems, e.g. (capacitated) vehicle routing, partitioning or even general integer programming, where finding an exact solution in reasonable time is, as of today, impossible (Sleegers et al. 2020; Peter Cheeseman, Bob Kanefsky, and William M. Taylor 1991). The alternative here is to use heuristics, i.e. algorithms that generate acceptable outcomes in a reasonable time. Today, many real-world problems such as scheduling, assignment, routing and/or logistics require heuristic approaches to solve large instances without a special structure (Gendreau and Potvin 2019; Martí, Pardalos, and Resende 2018).

While there is a lively debate about teaching classical mathematics to engineering students, published research on teaching operational research and discrete optimisation in higher education is sparse to the point of being non-existent. Neither the European Society for Operations Research (EURO) nor various national association have a working group or designated teaching streams as a regular part of their program and conferences. We found two reviews on teaching operations management in Spain, which point out the lack/absence of research into teaching methods (cf. Marin-Garcia 2018; Carmen Medina-López, Alfalla-Luque, and Marin-Garcia 2011). The more recent publication by Marin-Garcia (2018, 612) analyses the research focuses of 25 publications in Spain. He points out that a majority of publications have a research focus (unsuccessfully) aimed at finding a "silver bullet" teaching approach that works equally well for any student and context.

As such, what constitutes appropriate methodology to teach OR largely remains an open question. That is specifically relevant because, while OR draws deeply on discrete mathematics and computer science, it is fundamentally different from much of engineering mathematics teaching in that it does not provide fundamentals for other engineering classes but represents a skillset in itself.

In this work, we present a case study of an interdisciplinary Master's course on heuristic methods in the context of OR. We discuss to what extent well-established approaches from engineering education practice, such as Problem-based Learning (PBL), are applicable. Furthermore, we introduce two project cases and make a point that due to its application-oriented nature, OR specifically stimulates independent student work. To further foster discussion, we not only make the lecture notes are publicly available[2], but also provide all tutorial and project case data available to instructors upon request under a CC BY-NC license.

The paper is organized as follows: In Section 2, we introduce the course design, i.e. the learning outcomes and teaching contents (2.1), the structure of the course (2.2). This is then discussed in the context of active and problem-based learning (2.3). In Section 3, the above is evaluated based on the previously described data. Finally, Section 4 gives a summary and outlines both lessons learned and potential future improvements.

2 COURSE DESIGN

The context of this work is the interdisciplinary Master's course called "Mathematical Heuristics for Discrete Optimisation" (MaHeu) at RWTH Aachen University. The course consists of three main parts: a lecture, which takes place twice a week, a weekly tutorial session, and a practice case that students work on in teams. These three parts are interlinked. The lecture follows a PBL approach, where working sessions and practical problems are used to introduce students to relevant methodology, while relevant software is introduced and practiced in the tutorial. Both serve to prepare students to independently work on the case. In dealing with the case, the students work with data, implement their own algorithms, evaluate these computationally and discuss real-world applicability.

Grading is jointly based on a team grade for the project and individual oral exams. Upon successful participation, students are awarded 9 ETCS. Most participants take MaHeu as a compulsory elective subject in mathematics at either the Bachelor's or Master's level, or as part of their computer science Master's degree. The number of students finishing the course was 12 in 2019, 13 in 2020, 8 in 2021, 16 in 2022 and 21 in 2023.

2.1 Learning outcomes and teaching content

Following constructive alignment, intended learning outcomes (LOs) were formulated at course level (Biggs 1996). First, after successful participation, students *know major principles of both heuristics, metaheuristics and approximation algorithms.* Second, they *evaluate the necessity and suitability of using heuristics to solve given DO/OR problems.* Third, *they apply existing heuristics to established DO/OR problems*. Fourth and fifth, students *model novel, complex real-world problems mathematically* and they *modify and implement existing heuristics to solve those*.

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[2] https://combi.rwth-aachen.de/teaching/resources/MaHeu_LectureNotes.pdf

Sixth and finally, they *evaluate the suitability of such methods using both proofs and computational experiments*.

The first three LOs are addressed in both lecture and tutorial, and assessed in an oral exam at the end of term, together with the ability to perform mathematical proofs as asked for in the final LO. As part of the case, the other LOs are developed, and assessed in a presentation and a written report.

Note that single solution-based heuristics are a focus of this specific course, and population-based approaches, e.g. genetic algorithms are not covered in detail. However, an overview is given at the beginning of the term, which includes the optimisation cycle as standard approach to tackle optimisation problems the classification of algorithms and the main components of every heuristic. Then the difference between heuristics and approximation algorithms is discussed and the “no free lunch” theorem is introduced. Based on this, several fundamental paradigms for heuristics are covered in the following sections, as given in Table 1:

Table 1. Mathematical heuristics teaching contents.

Concept	Theory	Problems
Greedy	Different types of approximation ratios, series-parallel graphs	Minimum cost flow, set cover, k-center, Travelling Salesperson (TSP,) Independent sets and matroids
Local Search	Neighbourhoods	Machine scheduling, (Minimum degree) Spanning trees, k-median, Spanning trees with many leaves
Randomisation	Rounding, expected runtime, random approximation, Greedy randomized adaptive search procedure (GRASP)	Max-Satisfiability Problem (Max-SAT), Max Cut
Very Large-Scale Neighbourhood Search	Compound Swaps, DynaSearch, Eject & Reinsert, Lin-Kernighan	Machine Scheduling, TSP, Partitioning, Capacitated Minimum Spanning Trees
Simulated Annealing	Asymptotic Convergence	TSP

There is also a special section in the lecture on evaluation of algorithms that contains both evaluation techniques and practical content for doing computational studies.

2.2 Course structure

As discussed at the beginning of the section, the course consists of three elements: A lecture, a tutorial and a case. These are now covered in more detail.

Lectures take place twice a week. Small algorithm design and programming exercises are interspersed throughout the lecture, e.g. the problem of analysing the practical performance of algorithms and their comparison are introduced on the example of the traveling salesperson problem. The students work in small groups to discuss what questions should be answered by the computational study, and then perform an analysis on a given set of data via R[3] and compare their findings.

The lecture notes are provided digitally via RWTH's Moodle learning management system. Videos of past years are also uploaded and TikZ[4] based animations of all algorithms and concepts covered in the lecture are provided in an extra extension of the lecture notes.

The tutorial sessions take place weekly. Each week students are given a sheet with exercises to solve at home and then present next week. During the week, students send their solutions to an instructor who provides feedback. Some tutorial sessions specifically focus programming with domain specific software. This includes the statistics software R and the modelling language AMPL[5], together with CPLEX[6]/gurobi[7] as solvers. Those software packages constitute standard tools in optimisation/analytics that also offer free academic licenses. Students need to actively participate in the tutorial to gain admission to the exam. Here, active participation consists of presenting one or several solutions, with the number varying based on the number of participants.

Working on the case begins a month after the lecture/tutorial started and goes on for two months. Student groups work together in teams of four to six. At the end, students have to hold a final presentation and hand in a team report of up five pages.

For 2019-2022 the project was on the optimal wiring of heliostats for solar power towers based on previous research work of our group (see Richter et al. 2019). This year we updated the case to an operative surgery scheduling problem. Since real-world surgery data is subject to strict data protection in the European Union, we based the case on publicly available research data (see Leeftink and Hans 2018). Both projects were chosen because they address relevant real-world issues and they allow for the usage of simple heuristics to construct an initial feasible solution. The latter means that every group will be able to present some solution and students can differentiate themselves in terms of solution quality. Moreover, both cases are based on past (heliostats) and ongoing research of our group (surgery scheduling).

Note that the course itself is held in either German or English, depending on student preferences, and lecture notes, case description and tutorial exercises are in English.

2.3 Active and Problem-Based Learning

The course structure is specifically built on established educational practice in the context of engineering education. Active learning has shown to engage students in

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[3] See https://www.r-project.org/ .

[4] See https://tikz.net/

[5] See https://ampl.com/ .

[6] See https://www.ibm.com/products/ilog-cplex-optimization-studio .

[7] See https://www.gurobi.com/ .

the learning process and thus positively affect the acquisition of intended learning outcomes (Freeman et al. 2014; Prince and Felder 2006). Specifically, the combination of activity and variety has been shown to increase student interest, improve attendance and increase learning (Felder and Brent 2016; Prince 2004). This was used as a motivation to change the lecture content away from a standard frontal format towards a more active and student-centred design, and to ensure that the course itself is varied in terms of formats for students.

PBL is a teaching method in the context of active learning. The problem itself is used as context and motivation for learning (Prince 2004; Edström and Kolmos 2014). This is mirrored in Table 1, where each teaching content is interlinked with one or several problems. In each teaching block, these problems are used to motivate the corresponding solution techniques. Furthermore, students experiment on different problems and solution approaches themselves.

Note that allowing students a combination of experimentation, instrumentation, troubleshooting, modelling, self-directed and creative thinking, instead of a fixed sequence of tasks to fulfil, is also an important factor that contribute to the success of practical lab exercises (Felder and Brent 2016). We decided to support this through the real-world case. Specifically, the project description calls for students not just to identify the/one optimal solution but to test out different approaches and compare them based on knowledge acquired during the course.

3 EVALUATIONS

Course evaluation takes place through student coursework, weekly minute feedbacks and a final evaluation. This work is based on five years of teaching, i.e. the spring terms of 2019–2023. In 2020 and 2021, due to the COVID-19 pandemic, lecture and tutorial were held remotely.

All final evaluations are part of RWTH's quality management system. They consist of a range of items on a 5-point Likert scale ranging from 1 (very good) to 5 (very bad), and two fields for further comments, i.e. notable positive elements and suggestions for improvements. As the course and evaluation were held in German, all comments were translated to English.

Between five and nine students participated in the evaluations. Across all years, the overall grades were between 1 and 2 and no course nor instructor received an evaluation worse than 2 (good). In 2019 and 2020, students repeatedly remarked a lack of summaries as part of the lecture and marked down the corresponding item, those were subsequently added at the end of lecture content. During the COVID-19 pandemic, i.e. the spring terms of 2020 and 2021, multiple students remarked upon changed circumstances due to remote learning. Whereas some students mentioned the advantages of increased flexibility in learning and time saved due to not having to travel to university, others criticised the lack of personal interaction with both peers and instructors. In the exercise, the instructor offered an open digital meet-and-greet session before each exercise, which was received very well by students, although the fundamental criticism remained.

Across all years, students rated the module as providing an appropriate level of challenge and workload. As one student put it:

"As computer science student […] this was the first mathematics module that wasn't too hard because I lacked prerequisites […] nor to easy […] but demanding in a good way due to the complexity of the content. […]"

Students also remarked positively on both the course teaching: “The interactive nature of the lecture gets you to think for yourself an keeps you attentive.”, and the structure of the whole module: “The structure of the module with exercise, project work and oral exam is a welcome change.”

The weekly minute-feedbacks were divided into two parts: lessons learned, and questions suggestions for improvement. Students could voluntarily fill out the feedbacks. In general, students were diligent in filling out the feedbacks, specifically when it came to listing the topics covered in the last session. Questions frequently focused on formal definitions, e.g. “What precisely is the difference between general and problem specific heuristic?” or “How is an independence oracle defined formally?”, or they focused on follow-up questions regarding extensions of specific algorithms or e.g., general procedures for derandomization. However, most answers simply noted that students were happy with the course and enjoyed both teaching and content.

Generally, students’ reports were well crafted and their solutions made use of a range of different approaches. Frequently, either TSP or MST based heuristics were used as the starting point for the heliostat problem, with local search used for intensification. Similarly, GRASP procedures were frequently employed. Many groups also sliced the heliostat area into parts, making use its geometric structure. For the surgery scheduling problem, all groups started with variations of randomised GREEDY, though sometimes only as a baseline for comparison. Frequently, they extended their approaches with local search (GRASP), in multiple cases using improvement graphs to deal with large search neighbourhoods. Groups also implemented simulated annealing and integer programming based approaches.

In terms of evaluating their algorithms, as showcased in their report and final presentations, students used a range of mathematical tools from the lecture. By determining lower bounds for the best solution quality, they managed to estimate their solution quality. Furthermore, students analysed the run-time and memory requirements of their algorithms.

4 SUMMARY AND OUTLOOK

Based on student feedback, the active learning within the course and the project case were well received. Furthermore, the project reports and presentations showcased that students were able to implement techniques from the lecture and to modify them to suit their needs when dealing with a real-world problem. That indicates that the teaching approach successfully contributed to students achieving the learning outcomes, which is in line with established literature on active learning (Felder and Brent 2016).

It is notable that students remarked as an exceptionally positive fact that MaHeu only requires prerequisites that students had learned before. This would appear obvious, but it apparently is not – an issue for discussion within our faculty.

Furthermore, we find that operational research not only allows for, but indeed is well-suited to PBL and case-based learning. We believe that the OR and DO community would profit from sharing more respective teaching contents. In our case, both cases were based on our own group’s research and both cases can easily be extended to provide follow up work for students interested in a thesis, e.g. by including uncertainty, rostering or bed management in the case of surgery scheduling. This offers opportunities for both sides in terms of recruiting motivated students to be part of ongoing research work.

In the context of RWTH, it would also be interesting to compare teaching approaches. There is another lecture offered on heuristics optimization with comparable LOs for students from business administration and business engineering, but a very different teaching concept based on an inverted classroom paradigm with assessment through a written exam.

A possible extension for our course would be to offer different cases to each group or even set the groups based on case preference. While this does complicate grading and preparation, it also offers students more choices in determining their learning process.

Finally, we would like to point out that the absence of research on higher education OR and DO stands in stark contrast to the evidence-based and optimisation focus mindset of the communities. Closing this gap remains a challenge for both instructors and researcher in the field of OR and DO. Specifically, drawing from established research in engineering education may enable more successful teaching and learning not just generally, but also specifically in the field of OR and DO.

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INTEGRATING SOCIOTECHNICAL ISSUES INTO THE INTRODUCTION TO CIRCUITS COURSE

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ABSTRACT

Engineers frequently encounter sociotechnical issues in their work, so it is critical that they are prepared to address complex, real-world issues that require both technical and social expertise. Engineering accreditation criteria further underscore the importance of understanding sociotechnical issues by expecting engineering undergraduate programs to address ethical, global, cultural, social, environmental, and economic considerations in student outcomes. However, most engineering instructors were educated with a deep technical focus, have little experience outside of engineering, and feel ill-equipped to integrate non-technical topics. As a result, engineering is often taught in the undergraduate curricula from a purely technical perspective, with an emphasis on calculations and mathematical modelling, and without mention of social issues.

In this paper, we outline a new project to help engineering instructors integrate sociotechnical issues into their classrooms. Applying proven principles of backward course design and working with a team of electrical engineering graduate students, we aim to develop and test several sociotechnical modules for the Introduction to Circuits course. Each module will be linked to technical topics addressed in the course, and each will emphasize a different social issue. We will prepare detailed

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teaching guides so instructors can easily use the modules in their own contexts, and we will assess the effectiveness of the modules.

1 INTRODUCTION

Engineering is often taught in undergraduate curricula with an emphasis on calculations and mathematical modelling and without mention of social issues. But real problems are broader – they are multidimensional and interdisciplinary, and they encompass complex sociotechnical issues [1]–[4]. To prepare graduates for the workforce, instructors must equip students with both technical and social expertise.

Engineering accreditation criteria (e.g., ABET [5] and the European Network for Accreditation of Engineering Education [6]) further underscore the importance of understanding sociotechnical issues by expecting engineering undergraduate programs to address ethical, global, cultural, social, environmental, and economic considerations in student outcomes. Despite these criteria, however, typical engineering undergraduate curricula focus on the technical domain and often exclude social issues [7]–[11]. This focus reinforces normative cultural beliefs about engineering by inherently valuing technical issues and devaluing social ones, supporting the status quo of engineering as “objective”, and obscuring that engineering is done by, for, and with people [12]–[14].

Introducing sociotechnical issues into the engineering classroom can be difficult. Most engineering instructors have been educated with a deep technical focus, and though they may see the value of integrating sociotechnical issues into their courses, they often have little experience outside of engineering and feel ill equipped to integrate non-technical topics. Through this project, we aim to make it easier for engineering instructors to integrate sociotechnical issues into their classrooms.

Specifically, we will apply proven principles of backward course design and work with a team of electrical engineering graduate students to develop and test several sociotechnical modules for the Introduction to Circuits course. Each module will leverage fundamental circuits’ topics and will emphasize a different sociotechnical issue such as conflict minerals used for electronics or issues related to electric vehicle (EV) battery life cycles. We will prepare detailed teaching guides so instructors can use the modules easily in their own contexts, and we will assess the effectiveness of the modules in reinforcing both technical and social content of the module and in promoting students’ sense of social responsibility.

2 THE MODULES

Our sociotechnical modules will each integrate a specific social issue with relevant circuits’ content to help students see engineering as a sociotechnical endeavour. To maximize the learning potential of the modules, we will employ the principles of backward course design – including Understanding by Design [15] and principles of constructive alignment [16]. Accordingly each module will include learning objectives that address both social and technical considerations, post-class assessments (problems for homework and exams), and instructional activities that are all aligned with each other (*Figure 1*).

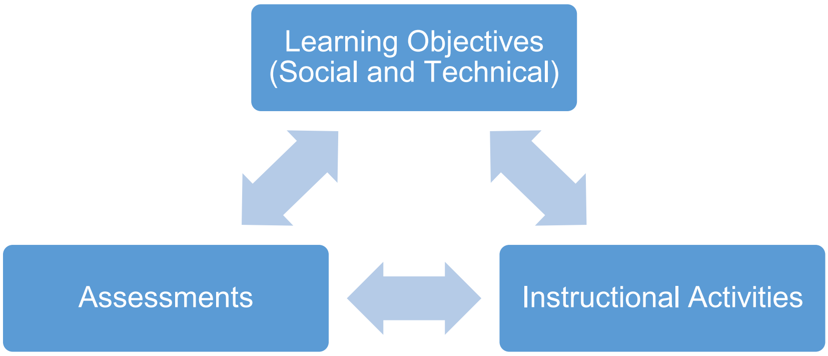

Figure 1. Backward course design

To make it as easy as possible for instructors to integrate the module into their courses, we will develop detailed teaching guides for each. The teaching guides will include sample slide decks, detailed lesson plans, and lecture notes. We will also provide assessment materials (e.g., sample homework problems and exam questions) as well as other resources to scaffold faculty in their use of the module.

2.1 Module 1: Conflict Minerals

As our first module, we will leverage an existing sociotechnical module that focuses on conflict minerals [17] and connects with basic circuits' principles of capacitors. It introduces students to social issues involved with mining of "conflict minerals" (e.g., tantalum, a material frequently used in fabricating the capacitors found in smart phones and other familiar consumer-electronic devices) in the Democratic Republic of the Congo. We outline learning objectives (which include both social and technical considerations), assessments, and instructional activities for this module in Table 1.

Students do some technical calculations related to capacitors, they discuss strategies and challenges faced by circuit designers in light of the social issues related to conflict minerals, and they research and present about different conflict minerals policies of several popular electronics companies. Finally, students make a critical comparison of the conflict mineral policies for various companies and reflect on their role as engineers. Homework for the module is integrated into regular class assignments, and technical calculations as well as oral presentations and discussion are included in the module.

Table 1. Learning objectives, assessments, and instructional activities for Module 1

Learning objectives	Assessments	Instructional activities
• Analyze capacitors as electrical devices • Define conflict minerals and describe at least two social issues surrounding them • Describe where conflict minerals are used • Describe potential options for engineers concerned with the social implications of conflict minerals	• Complete calculations and internet research about conflict minerals • Prepare presentation about conflict minerals policies and social implicatons	• Learn about and discuss conflict minerals and the social implications • Present research about conflict minerals policies

2.2 Module 2: EV batteries

Our second module focuses on issues related to life cycles of EV batteries [18], and it connects with basic circuits' principles of the voltage divider. It introduces students to issues involved with the growing number of end-of-life EV batteries and concerns related to recycling them by applying principles of the circular economy. We outline learning objectives (which include both social and technical considerations), assessments, and instructional activities for Module 2 in Table 2.

Table 2. Learning objectives, assessments, and instructional activities for Module 2

Learning objectives	Assessments	Instructional activities
• Design a voltage divider for a DC voltage source to illustrate repurposing EV battery packs • Estimate the energy available in end-of-life EV batteries • Describe social risks introduced by recycling EV batteries that could be alleviated by applying circular economy principles.	• List various social risks introduced by recycling EV batteries • Write about the principles of the circular economy and how it can be applied to repurposing EV batteries • Use a loaded voltage divider model to calculate voltage, resistance, and power of a second life EV battery pack • Estimate the effect of energy degradation on EV battery repurposing.	• Listen to a podcast about the circular economy and answer some related questions • Estimate and discuss the future voltage capacity of existing EV batteries and the potential demand that could be met using them • Learn about the circular economy and how it relates to circuits concepts and EV batteries • Discuss ways to use the circular economy to repurpose batteries.

2.3 Additional modules

To develop additional modules, we will recruit a cohort of electrical engineering graduate students from across the U.S. We will design a workshop to introduce the cohort to both proven course design principles and the importance of integrating sociotechnical topics into traditional engineering courses. The cohort will then collaborate to propose a series of sociotechnical modules for the Introduction to Circuits course, and they will ultimately prepare detailed teaching guides for each.

We expect that establishing a cohort will introduce diverse perspectives into the module design and will create a sense of community among the graduate students as they tackle the challenging tasks related to developing the modules. Students in this cohort will be able to help recruit instructors to implement the modules at diverse institutions, and they will themselves be prepared to implement the modules in their own courses and to include sociotechnical content in their teaching when they become professors. Using a cohort approach in this way will hopefully increase the likelihood of changing the culture of electrical engineering teaching broadly.

3 ASSESSING THE IMPACT OF THE MODULES

As we introduce our modules, we will evaluate the extent to which they achieve both the social and technical learning objectives. Because we will have applied proven course design principles, we will do this by studying student responses on the assessments. Specifically, we will review student solutions to the relevant homework assignments and exam questions and will summarize student responses to open ended reflection prompts, thereby generating evidence about how well they achieve our learning objectives.

We will also assess the impact of the modules on students' social responsibility attitudes (i.e., their sense of social responsibility and their adherence to normative engineering cultural beliefs). To do so, we will conduct student interviews and focus groups, and we will develop and administer a student survey instrument as a pre- and post-course assessment measure. The survey will include a combination of pre-tested and previously validated survey items as well as demographics items (e.g., sex, race/ethnicity, class level, and field of study). Key components of our survey, include a subset of items from the Engineering Professional Responsibility Assessment instrument (EPRA, [19]) to assess students' social responsibility attitudes and items from a published survey about engineers' training in professional responsibilities [20] to assess students' adherence to normative cultural beliefs.

4 NEXT STEPS

We plan to test and deploy each of the modules using a four-stage process:

1. Pre-pilot the module in a small circuits course at a small, private institution taught by a member of the research team
2. Pilot the module in a large circuits course at a large, public university taught by another member of the research team
3. Launch the module in large circuits courses at the same large, public university taught by an instructor not part of the team
4. Deploy the module in at least four other courses at diverse institution types (including minority-serving institutions and specialty schools)

We will refine the modules at each stage using student and instructor feedback.

Our project is a work in progress. To date, we have developed and pre-piloted Modules 1 and 2. After developing our student survey, we will pilot those two modules and then launch them broadly. We have just begun to formulate our plans for the electrical engineering graduate student workshop, and we will start recruiting students soon. We expect to be able to broadly disseminate our project findings and share detailed teaching guides with instructors across the globe within a few years.

5 ACKNOWLEDGMENTS

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Mentoring programs for engineering students as a way to improve their skills and competencies

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Conference Key Areas*: Mentoring and Tutoring and Recruitment and Retention of Engineering Students.*

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ABSTRACT

Universidad Francisco de Vitoria (UFV) in Madrid (Spain) and Universidad Vasco de Quiroga (UVAQ) in Morelia (Mexico) seek the comprehensive academic training of students: not the mere development of technical skills, but also the personal and soft skills that enable them to face their professional reality.

Educational missions in both institutions aim for sustainable development oriented towards people and the societies in which they are immersed. Their substantial actions have been designed, in such a way that active methodologies and innovative proposals are included. Among them, it is worth highlighting the provision of a personalized support system for students, in which, through a competence itinerary with their tutors, issues are addressed to help them to full development.

An added value has been identified by applying this mentoring system at engineering programs (mainly based on hard skills), when supporting students in the development of other skills.

A comparative study was carried out on the differences and similarities of the programs of both universities, from the point of view of the people who mentor and guide students. Thanks to those contributions, we have information that will allow us to adapt the processes and thus respond more adequately to the needs of engineering students in their first undergraduate degree courses. The focus group technique and a survey were used in the process.

1 INTRODUCTION

1.1 Background

The word accompany comes from Latin *cum-pane*, i.e., to share the same bread, literally “with bread”. It means that we are together in the process, putting both lives at stake, with their different degrees of experience, to reach mutual learning (Nicholson 2021, 281-290).

Accompanying is a human response that comes from the heart, and it is focus on the other needs. It means to walk together (who accompany and the accompanied person), and allow the other be, letting him awaken his own being. To accompany is to be, to welcome, to listen, to share, and to go out to meet the other. Accompanying is an art because the success of the accompaniment is not that of the one who accompanies, but that the other acknowledges feeling accompanied. Time is required to accompany, silence is required from one to listen to the other, and it is necessary to change the rhythm and adapt to the other. The one who accompanies does not advise, does not have magic recipes, but seeks to illuminate from his own experience those of the accompanied. Accompanying is fundamentally the action of “walking next to” a person, sharing some part of his/her itinerant life. Accompanying is, in various ways, sharing the journey and their experiences (Kaufman et al. 2022, 33-45).

1.2 Mentoring at UFV

Mentoring activities developed at the UFV in the first year of Industrial Engineering students are framed in the Knowledge Management and Human Skills (KMHS) course, offered annually with recognition of 9 credits in the student's curriculum (Queiruga-Dios, et al., 2023, 907).

Mentoring process includes student's individual accompaniment, through a mentor, who is a professional trainer equipped with the necessary competences to perform this task. During classes students are accompanied by their teacher and their classmates, they are part of a community. The KMHS course aims to contribute to the comprehensive training of the student, it is a compulsory transversal and propaedeutic subject that proposes the acquisition of competences and skills through a comprehensive experience. This course is developed as an experience made of different actions. The acquisition of competences becomes a means of personal fulfillment by asking the student a question -"what do these professional skills have to do with me, with my vocation and with who I am?; and how can I live those competences with sense?"-, and then, invite him or her to discover a possible answer: that their future career depends to a great extent on how that student build him or herself today (Allen et al. 2004, 127; Crespí 2022, 852-873).

The process of accompanying students is developed through 6 meetings with each student. During these sessions, a specific route of discovery is presented to students, through questions, exercises and actions that allow them to make decisions throughout their first year at university. These meetings seek that the student acquires competences as specific as proactivity, time management, deep insight, etc. This process is carried out through questions that challenge the student to generate creative habits, and using the CRECER methodology, i.e., with Concrete, Realistic, Empathic, Programmed, Focused, and Challenging actions (CRECER is the Spanish acronym that specifically means *grow* in Spanish) (Díaz-López, 2022).

1.3 Tutoring at UVAQ

The objective of the personalized accompaniment program at UVAQ is to go along with students in their integral development, focusing on 5 of the dimensions of the person: physical, psychological, academic, social, and spiritual, through the support of tutorials, growth workshops and personalized psychological care.

The establishment of an aid and accompaniment relationship arises from students and tutors contact during classes and from scheduled individual interviews. Students have the possibility of accessing two tutoring sessions throughout the semester, during which they have a space and time to share their experiences, ways of thinking and feeling, in the same way that they explore and discern about their lives, supported and guided by the tutor. These interviews take place at the university campus.

The tutor is the person who accompanies the student throughout the training in the personal, spiritual, psychic-emotional field. The tutor has a moral and spiritual sense, trained to develop this specific function. He or she has a competent academic level based on humanist and learning theories to help young persons on their way during their time at the university. Tutors task is to serve, because they have the knowledge, experience, training and maturity to assist and attend students (Burgess, van Diggele, and Mellis 2018, 197-202).

Currently, the work team for the tutoring of the personalized accompaniment program is made up of thirteen tutors and three external specialists in Psychology. The specialists and the tutors attend to training sessions organized by the educational guidance department. This training is given twice a year in an inter-semester period to deal with the necessary issues for the development of their activity.

The student's commitments with the personalized accompaniment program are the following: To know themselves, to develop and discover their abilities as a person; to have a commitment to the tutor in the development of the activities agreed upon by mutual agreement and become aware that the only person responsible for their training and growth process is oneself; and to participate in the tutor evaluation processes, in accordance with the mechanisms established by the university.

2 METHODOLOGY

A mixed methodology has been chosen for this study. First, an ad hoc questionnaire called “UFV mentoring-UVAQ tutoring for engineering students” has been conducted, based on qualitative questions. Second, a focus group has been held with the agents involved in the study. Both instruments have provided a global vision of the two accompaniment systems and have made it possible to compare them. The focus group stands out especially, because it made possible to know each other and develop this cooperative and collaborative study.

The focus group has its origin in the qualitative method of the interview, but tries to cover more agents, so that different opinions can be collected at the same time, in addition to generating a highly enriching dialogue between the parties. It is a method that lies between a meeting and a conversation, defined by some authors as a debate among a group of people, on a specific topic and with an experienced moderator (Hauer et al. 2005, 732-734; Sim and Waterfield 2019, 3003-3022).

The chosen sample was made up of advisors and mentors who accompany engineering students from the UFV and UVAQ universities. Students who have participated in the accompaniment process could have been chosen to tell their experience of the accompaniment system of these universities, but on this occasion, it has been preferred to carry out a self-analysis by those who do the accompaniment work in order to better understand both support systems and enrich themselves with the benefits of each of them. This methodology has been chosen because it provides great qualitative information (Gundumogula 2020, 299-302).

Qualitative analysis through focus groups serves as a channel for dialogue between the agents involved through which opinions, concerns, good practices and experiences are shared. In case of the UFV, the sampling of this study is of a non-probabilistic type by judgment or deliberate. Of the 270 mentors, only those who carry out their work in the polytechnic school, in the Systems Engineering degree were chosen. At the UVAQ, only those who currently carry out their work in the Faculty of Engineering were chosen.

3 RESULTS

A group of eight teachers participated in this study, 75% corresponded to women and the remaining 25% to men, 25% being mentors from the UFV and 75% tutors from the UVAQ. Specifically, the faculties in which participants developed their work as mentors were Systems Engineering and Computer Security, Computer Engineering and Systems Engineering.

On average, mentors have developed their activity for 6.2 years. However, the dispersion of the values is significant (with a standard deviation of 6.15), since some of the teachers have less than 1 year of experience as mentors, while others have 15 years of experience. Fig. 1 shows this distribution, grouped by the experience of the teachers/mentors who participated in the study.

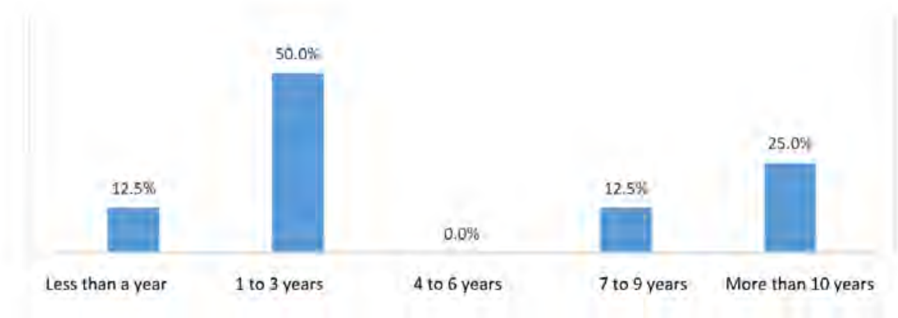

Fig. 1. Experience of the teachers/mentors

Regarding the experience of the mentors in engineering accompaniment, it was found that the majority have worked as tutors between 1 and 3 years. It is important to highlight that 37.5% of the consulted mentors have more than 3 years of experience and only 12.5% have less than one year of experience in processes of accompanying engineers.

3.1 UFV mentoring-UVAQ tutoring for engineering students

The instrument "UFV mentoring-UVAQ tutoring for engineering students" was applied to the teachers who carry out this work, having a total of eight answers related to the tutoring tasks and the advice that this implies. The following questions were proposed:

1. What has been the most difficult experience you have had as a mentor/tutor?
2. What has been the most satisfying experience you have had as a mentor/tutor?
3. Write a word that explains what to be a mentor/tutor means.
4. What do you think are the strong points of the student accompaniment system in your institution?
5. What do you think are the areas for improvement in the student accompaniment system in your institution?

Regarding the experiences classified as difficult that were obtained by the mentors/tutors, an open option was chosen, which allows a better approach to the qualitative logic of their own experiences. These open responses were categorized, and some of them appears repeatedly throughout the results: problems related to students suffering, the difficulty in helping young people to process their emotions and anxiety management, and the presence of violence in students' life, even a kidnapping case significantly affected one of the students.

In general, personal aspects related to the mentor or tutor tasks were not mentioned, the answers were oriented to the intrinsic difficulties of working with people who are going through complicated situations in their lives. The terms that were mentioned most frequently were: loss, suffer, pandemic, mourning, anxiety and violence.

Tutors and mentors were asked about those gratifying experiences related to their work as tutors/mentors during student's accompaniment. Once again, the open responses were categorized and a diagram was generated (see Fig. 2), which shows the network of most frequently mentioned concepts and the interaction between them, being the keywords: accompaniment, students and improvement, and the rest of words are the pleasures that give meaning to the keywords.

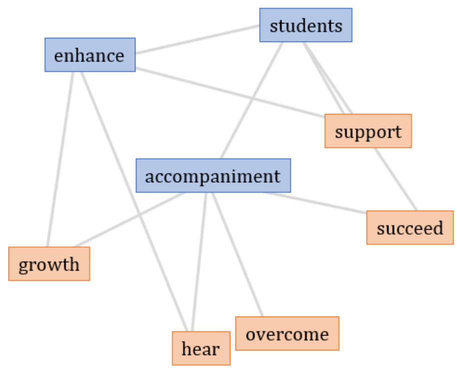

Fig. 2. Chart with key descriptors of the most satisfying experiences you have had as a mentor/tutor

When questioning the mentors about the strong points of the program, they identified its comprehensiveness, the constant training of the tutors, the promotion of spaces for reflection and self-knowledge in the students through active, empathetic and an active listening, free of prejudices, as well as a space that provides containment and that allows guiding students with psychological or psychiatric care (when needed) (Fig. 3).

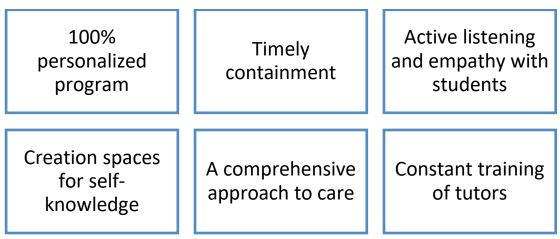

Fig. 3. Strengths in the student accompaniment system at its institution

Finally, tutors were asked about the improvement possibilities that they identify in the student accompaniment system (in their own institution), and they pointed out the need for the tutors to have an adequate number of students that allows them to maintain a personalized treatment, to have better spaces for tutoring and mentoring sessions and increase the time dedicated to them.

This opinion poll allows us to get some results from people who face the day-to-day work of tutoring students in the institutional support systems from the Francisco de Vitoria University and the Vasco de Quiroga University and becomes a very important input to improve the service offered, while providing better support to mentors and students in a process that seeks to be comprehensive, empathic and humane.

3.2 Focus Group

With the group of eight teachers, a focus group was raised to discuss about the following issues:

1. In general, what would you say about the characteristics of first-year undergraduate students?
2. Specifically, what are the characteristics of engineering students? (brief description using adjectives).
3. Do you think engineering students have specific needs compared to other students in other degrees? (Only aspects that appear different or significant compared to other students).
4. Do you think that students positively value the accompaniment provided by their university? Why?
5. In what aspects do you think we can help engineering students?

In the case of the first question, mentors and tutors consider that students who are more confident in terms of the degree they have chosen, feel excited and eager to start this new stage of their lives and therefore they show a high level of motivation.

In recent years mentors and tutors show an increase in social immaturity on several students and great affective needs that they can verbalize naturally. This could be a consequence of the pandemic.

Regarding the second question, the mentors and tutors of engineering students rate them with the following adjectives: students who are especially organized, competitive, responsible, and with high levels of self-demand. Again, they speak of having a certain immaturity and irresponsibility in some cases, especially when they do not find the necessary motivation, with little contact with emotion or only superficially. A generalized apathy towards issues that have nothing to do with their discipline is perceived. In the case of engineering majors, there is a male majority, and it seems that this makes it difficult for them to express their emotions (in this sense, tutors and mentors point out that it may be something cultural). They also describe them as reserved, with logical and mathematical thinking, skilled in process issues, and with certain difficulties in relating.

Answers to the third question revolve around the emotional issue, reiterating that they are less expressive, have a hard time expressing their emotions and are more reserved than students in other grades.

Regarding the fourth question, all the mentors and tutors understand that yes, the assessment of engineering students is positive, but that in most cases it is difficult for them to understand what the support offered by both institutions means and they tend to start the processes. quite closed, but when they understand it better their attitude changes radically, they are open to the process and appreciate it.

Finally, to the fifth question, the answers refer to maintaining an attitude of listening and permanent availability with them, creating with them a safe environment in which they can tell about the situations they are going through without being judged. Added to this is the need to provide them with information on what the accompaniment programs consist of. Another answer raises the possibility that one way to help students is precisely not to label them for what they are or how they are, to give them the space to be themselves.

4 SUMMARY

Accompaniment is a fundamental tool in the teaching-learning process. It provides students with a safe environment in which they can be themselves, be able to express their concerns and difficulties, and seek, with the help of others with more experience, the path to reach their goals.

Mentors and tutors report that the most difficult situations they have addressed in their work are the emotional wounds and suffering that students show in difficult situations. At the same time, the most rewarding experiences are related to how students deal with these situations and how they can generate an interpersonal relationship with the mentor or tutor. Despite the difficulties faced by first-year engineering students, such as poor socialization or difficulty to express their emotions, thanks to the accompaniment they can significantly improve these aspects according to the perception of mentors and tutors.

Both mentors and tutors highly value their work, expressing great personal satisfaction for working with students. It is important to them to see how students mature personally in the first year of their degree. As one of the trainers shared in the focus group: “it is a gift to be able to look into the lives of the students, who simply share with us who they are; it is a gift and a responsibility, because we are treading on sacred ground”.

To continue developing their work, mentors and tutors consider that it is necessary to adapt the times and spaces with the students, to share more sessions with them, going deeper into the topics already proposed in the process, as well as to adapt the number of students per mentor/tutor so that they can develop their tasks with quality.

5 ACKNOWLEDGMENTS

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INVESTIGATING THE PERCEPTIONS OF SCIENCE AND ENGINEERING UNIVERSITY EDUCATORS AND STUDENTS AROUND SUSTAINABILITY INTEGRATION AND THE ROLE OF DIGITAL TOOLS

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***Keywords**: Sustainability integration, educational software, staff and student surveys, materials education workshop, whole institution approach*

ABSTRACT

Last year we presented the first phase of our on-going research project - a collaboration between researchers at UCL and Academic Development team members at Ansys Ltd on sustainable digital transition in education. The results of the first phase were published in proceedings of the 25th International Conference on Interactive Collaborative Learning (ICL2022). We developed a framework to explore how technology companies, with a focus on education, approach sustainability in education through their products and their practices and what makes them impactful, focusing on a specific case of Ansys Granta EduPack.

The framework was the amalgamation of two previous analyses that explored i) how learning outcomes associated with the UN Sustainable Development Goals could be used to foster ways in which learning for sustainability can be implemented in Higher Education, and ii) how the same learning outcomes translate to concepts of capital used by companies to assess sustainability impact.

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In this part of the study, we present the second phase of our project, the development of two questionnaires for university students and educators based on the framework, described earlier. The questionnaires focus on assessing sustainability awareness and involvement of staff and students of Science and Engineering Departments in sustainability activities, using a Whole Institution Approach.

In this paper we present preliminary data from the piloting of the questionnaires during a materials education workshop for University Educators organised by Ansys Ltd in Cambridge UK. In the third phase of this research project the questionnaires will be shared more widely with staff and students in science and engineering focused faculties internationally.

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1 INTRODUCTION

1.1 Sustainability as an Institutional dimension for Universities

Sustainability is a crucial institutional dimension for many Universities as students have been shown to select University departments to study based on their engagement with sustainability and recent surveys they have calculated that 88% of all undergraduate students in the UK would like their courses to be directly related to sustainability and the UN SDGs (Students Organising for Sustainability 2022). Impact and value creation at the job environment is also a factor influencing how recent graduates choose a work place and to quote the above mentioned survey:

"… the majority of students still say the chance to work in an organisation that makes a difference to environmental and/or social issues is something they would consider at the application stage but 77% would accept an annual salary sacrifice of £1000 to work for an organisation that has a good environmental and social record, down from 80% in 2020-21." (ibid)

Sustainability is an interdisciplinary topic and many Universities are recognising the need to equip their students with skills for sustainability as they will enter a complex world of unprecedented change in which they will have to make crucial decisions (Lozano-García, Huisingh, and Delgado-Fabián 2009). Universities are embedding sustainability as either a module within specific disciplines, an elective course that students can take as part of their University studies, an interdisciplinary programme of study at postgraduate level usually and less so at undergraduate level or they are trying to reform their curricula so they embed it as content and pedagogy which is the most complex of all (Kioupi and Voulvoulis 2022).

However, for a University to be truly sustainable, it usually has to embed sustainability using what is called the Whole Institution Approach (WIA) as advocated by UNESCO (Wals 2014). This approach talks about engagement with sustainability through all the dimensions of the institution that is through research, teaching and learning, governance and operation as well as community engagement. This is thought to be a systemic approach to integrate sustainability in an institution as it enables a change of culture in the University and requires committed and inspiring leadership, usually of a transformative nature (Tilbury 2011). It starts with integrating sustainability to the vision and mission of the University so it guides its strategy in how the university operates, does research, provides education and relates to internal and external stakeholders. Some steps on how this can be achieved in terms of using the SDGs as a guiding framework have been discussed in the literature and can be useful in helping University stakeholders start a discussion on what this would look like in their University (Kioupi and Voulvoulis 2019).

Apart from greening the campus initiatives which are important for offering a lived experience of sustainability for students and staff and offering engagement opportunities beyond specific roles, Universities have a social role to fulfil which is linked to the research they conduct. This in the times of existential crises we are currently being faced with could be related with providing solutions to challenges related to the SDGs or even ways forward e.g. solutions to climate change, safe water access, sustainable urban environments or even combating inequality and poverty (Lukman and Glavič 2007; Australia/Pacific SDSN 2017). Through the education they

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offer they can empower their students with sustainability competences, which are complex constellations of knowledge, skills, values, attitudes and behaviours that have to do with tackling problems holistically but also with imagining and enabling alternative sustainable futures (Kioupi & Voulvoulis, 2022). With regards to community engagement, Universities are starting to develop hubs, such as living labs, community spaces in which different departments contribute as testbeds for sustainability but also relationships with local communities, organisations and businesses to offer solutions or to co-produce knowledge with citizens and other professionals and come up with innovative ideas e.g. maker spaces (Leal Filho et al. 2019).

One important area of sustainability integration within a University's teaching practice is through the digital transition and technology companies can be useful in linking their educational offering to clear educational outcomes that will benefit the University's transition as well as help students and staff develop digital skills. This paper links our previously published framework for assessing sustainability integration in educational products of technology companies with the views of educators and students on educational outcomes for sustainability through the design and testing of quantitative measures that aim to research views of how Universities are incorporating the WIA in their realities as well as how educational software for sustainability is perceived and utilised.

1.2 Background and rationale

Sustainable digital transition (SDT) is the name we are using to describe the integration of sustainability in the digital economy and it is linked with "greening the economy" efforts as well as with creating enabling policy to allow for innovation related with environmental, economic and social targets (European DIGITAL SME Alliance n.d.). Education is an important part of the economy as it is related with skills essential for the workforce, as well as with innovation and tackling of pressing challenges. So there is also an effort towards the sustainable digital transition of education by the integration of the UN Sustainable Development Goals in education (Kioupi and Voulvoulis 2019, 2020; Sachs et al. 2019).

In the first phase of our case study, we observed that the SDGs were attached to learning objectives that could be used to influence the cognitive, socio-emotional, and behavioural learning of students (UNESCO 2017). Thereby, the SDGs can contribute to sustainability awareness raising among students. However, in their original form the SDGs were too complex to implement in education. We also observed that the products and practices of EdTech providers had an influence on student learning, although it was not initially clear how the products and services related to learning objectives. We developed a framework to explore relationship between the SDGs, learning objectives, EdTech products and practices. To aid our comprehension we focused on the use of Ansys education-focused software. Details of the framework can be read in a previous publication (Vakhitova et al. 2023).

The findings of the framework indicated that EdTech providers use their CSR (and CR) reports to demonstrate their approaches towards sustainability. In these reports sustainability was viewed as different forms of capital (Maack and Davidsdottir 2015), two of which (human and social) aligned well with the learning objectives of courses that link to sustainability and were aligned in the used Ansys products. We then

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identified which of the SDGs were attached to the learning objectives associated with human and social capital using a previously published framework for integrating the SDGs into educational programmes that takes a systemic approach instead of accounting for separate SDGs (Kioupi 2021).

We highlighted that the framework offers a consistent way by which sustainability integration in digital tools/educational software can be assessed using environmental, social and economic capitals (M. Ashby 2015) as well as enabling conditions for the UN SDGs (Kioupi and Voulvoulis 2020) as demonstrated in the case study of Ansys Granta EduPack (Vakhitova et al. 2023; “Ansys Granta EduPack | Software for Materials Education” n.d.). This fills a gap in the existing literature and practice and allows both educational institutions, such as Universities, and EdTech companies a coherent way of providing evidence of the links to sustainability of their programmes and services but also provides a way to link with learning outcomes and quantify the impact on student learning and sustainability competence development.

Usually sustainability integration in education, is representative of a top-down approach, originating from bodies, organisations and businesses outside of the educational institutions in which the changes are to occur, which provide the guidelines to educational institutions to do so. Furthermore, the alignment between the SDGs, learning objectives, EdTech products and practices, is characteristic of an incidental approach towards sustainability whereby raising awareness among students is an additional benefit rather than an intended outcome (Brinkhurst et al. 2011). The incidental nature of the relationship between the SDGs, learning objectives and EdTech implies that further exploration is needed through the validation of our framework.

Previous literature advocates the use of questionnaires to measure attitudes and behaviours regarding sustainability. Gericke et al. (Gericke et al. 2019) presented their investigation of Sustainability Consciousness - “an individual’s experience and awareness of sustainable development”. To gather individual views the researchers used a questionnaire, which explored three key aspects of consciousness, these being Knowingness “the state of mind in which a person thinks something to be the case” Attitudes & Behavior. All three aspects are similar to our focus on exploring the cognitive, socio-emotional, and behavioral learning of students (UNESCO 2017) which implies that a similar construct would be appropriate for the second phase of our case study.

At present, the first phase of our case study has explored how EdTech providers approach sustainability in education through their products and practices. However, to fully explore what makes EdTech products and practices impactful regarding sustainability, we need to obtain the views of faculty staff and students. These views are representative of bottom-up perspectives (of students) and often overlooked middle-out perspectives (of faculty staff). We will look for alignment between the top-down, middle-out and bottom-up perspectives. In the second phase of our case study, we will deploy a whole-institution approach (WIA) to explore the extent of sustainability awareness and integration among faculty and students, following the below definition of a WIA:

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A "whole institution approach" means that all aspects of an institution's internal operations and external relationships are reviewed and revised in light of SD/ESD principles… A whole institution approach means that the strategy of the institution, and ultimately its culture, is oriented towards sustainable development." (UNECE 2008)

The extent of alignment between the perspectives would be an indication of what makes educational technology products and practices impactful in education. Strong alignment may be indicative of co-ordination and collaboration between faculty, students, and EdTech providers. Weak alignment may suggest that SDT in education is incidental and lacks co-ordination. In both scenarios it may be possible to identify strengths and weaknesses of SDT enabling more coherent strategies to be created and deployed.

2 METHODOLOGY

2.1 Design and development of surveys to gauge student and staff experience of sustainability in Universities in the UK

We are focusing our research on how Universities practice sustainability and we wanted to understand how they embed sustainability through WIA. We are focusing initially in the UK and in departments related with science and engineering but we want to expand to departments with orientation to social studies as well as to those outside the UK. This will allow us to collect data from diverse Universities and map what they are doing but also how students and staff are experiencing these efforts. To start our research and establish a baseline of how sustainability is practised we developed two questionnaires to understand how University educators and students engage with sustainability on and off campus. The questionnaires were built using previously published and validated questionnaires as well as we included some new questions that would allow us to cover as many aspects of the WIA as possible as well as to collect data on how Universities are using educational software related to sustainability (Barth 2011; Gora et al. 2019). The use of technological educational solutions (software) is a promising way to engage students with sustainability and the development of students' digital skills is crucial from an employability point of view.

The questionnaires include four areas of engagement with sustainability: curricular, institutional, research-based and community-based. The questionnaire for University staff also includes a question about the use of educational software. The questionnaires include mostly close-ended questions answered on a Likert scale on a Not at all to A great extend range, including a Don't know answer, yes/no/don't know options or a sliding scale and some open-ended questions to gain more descriptive and qualitative information about the aspects of sustainability they feel are already integrated or they would like to see integrated in the future.

The student questionnaire includes 12 questions and starts by asking if the students are undergraduate or postgraduate what is their University and department at its introductory part. It also asks about courses offered in relation to sustainability as well as any curricular integration of it and seeks to also check for any gaps the students can identify in their curricula. The next section is about the sustainable use of resources and the enhancement of biodiversity as well as the provision of opportunities for the community on and off campus to engage in new connections and solutions building for sustainability. The final part is concerned with the opportunities

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that are specific to students in relation to their engagement with sustainability on and off campus.

The staff survey starts in a similar way and includes 16 questions, it asks about staff professional role in the university, University name and department. Then it goes on to questions about curricular integration of sustainability and identification of gaps as well as sustainable use of resources and community engagement with sustainability. Then it includes a section about opportunities for research related to sustainability for staff and students, professional development offered to staff in relation to sustainability integration and criteria for employment related to sustainability. The final section concerns collaboration with technology companies and the use of educational software in the area of sustainability that they are already engaging with or they would like to in the future and the areas that they would like to address.

To increase the questionnaire reliability and validity we asked colleagues from the Department of Physics and Astronomy at UCL to review them and provide comments to us. We also asked a group of 8 Year 3 students from the same department, who were engaging in an open project that links Physics and engineering with sustainability, to check for areas of difficulty and provide feedback. They were shared with colleagues and students at ETH Zurich for their consideration and feedback as a target population outside the UK so the relevance of the questions to audiences outside the UK could be increased. The questionnaires were improved based on the comments, received and finalised for submission for ethics approval by UCL (this process has not been finalised yet). The next step is the dissemination of the questionnaires in UCL, other UK Universities and then abroad, followed by the data collection and analysis. A part of the staff questionnaire was used for collecting responses from participants at the “Teaching Sustainable Development using Ashby’s 5-step method” workshop that took place in Cambridge UK (3/4/23), helping to gain initial insights. It is described in the next part of this paper. The process of developing and validating the surveys is presented in Figure 1.

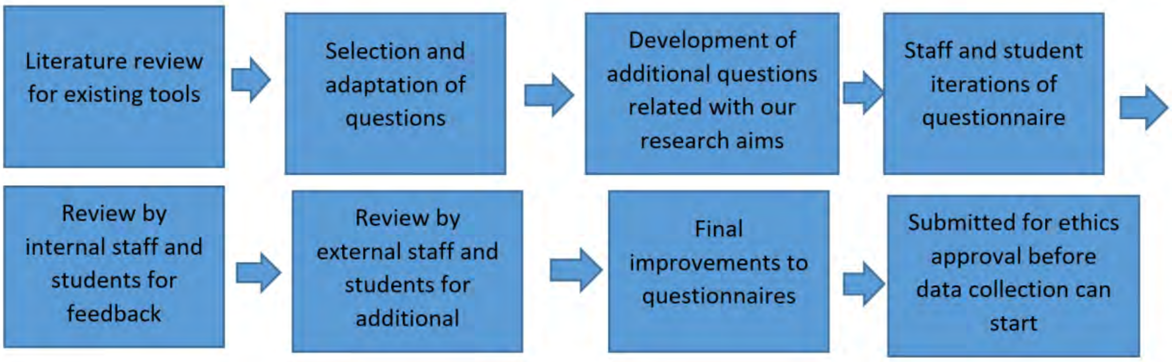

Fig. 1. Flow chart that shows the steps of questionnaire development.

2.2 Materials Education Workshop

On the 3d of April, as a part of the International Materials Education Symposium, authors from Ansys Ltd (Academic Development Team) held a workshop, dedicated to Materials and Sustainability, named “Teaching Sustainable Development using Ashby’s 5-step method” (link to the workshop). The Workshop was based on

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developments in Mike Ashby's second edition textbook "Materials & Sustainable Development" (M. F. Ashby, 2022). The workshop material (templates and slides)("Ansys Education Resources – Teaching Materials" n.d.) was used in teaching for several years in various educational establishments, aiming, among others, to support educators from technical educational establishments, embracing the social element of sustainability assessment ("Paper: Social Life-Cycle Assessment and Social Impact Audit Tool | Ansys" n.d.). This workshop has encouraged discussion on sustainability integration in engineering curriculum among participants.

The fourteen participants of the workshop, representing 10 different countries, came from various universities around the world, including Canada, Australia, mainland Europe and from the UK. These were predominantly at a level of teaching staff in engineering/materials field or combining a role in administration of education process at a university. After the workshop participants were asked to fill in a part of the staff questionnaire (6 first questions regarding Sustainability in Curriculum at Departmental Level), we have described in the previous section. The purpose of the survey and the research project was explained, and the anonymity of their responses was guaranteed. All participants agreed to complete and provided their responses to the survey.

3 RESULTS AND DISCUSSION

3.1 Materials Education Workshop results

The overall results from piloting the survey at the materials education workshop are presented in Table 1.

Table 1. Results from the main areas of the survey, distributed at the workshop Materials & Sustainable Development (3/4/23)

	Questions / Answers	Don't know	Insufficient	Sufficient	None	More than enough	Total responses
1	Sustainability courses		10	4			14
2	Global Warming/Climate Change/Science	1	7	4	2		14
3	Clean Renewable Energy/Critical Materials	1	9	4			14
4	Globalisation & Sustainable Development Goals	1	10	1	2		14
5	Curriculum/ teaching activities*		9	2	1		12
*2 participants have not responded to question 5							

Despite being a relatively small sample, the participants are the people from our target group. These are the individuals, involved in teaching with an interest in sustainability at materials, design and wider engineering faculties around the world. We will further collect data distributing the survey across universities and compare these initial results.

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The key conclusions suggest there is still a gap in the inclusion of sustainability in the curriculum in most of these universities, specifically there is an insufficient number of courses focusing on sustainability offered at higher education establishments. The most disregarded is the topic of Globalisation and Sustainable Development Goals, as well as Climate Change and its Science, showing that crucial international policy developments such as the Paris agreement and the UN SDGs are being left out.

Some of the discussions have focused on the need for a greater collaboration among scientists and engineers and academics from arts/humanities areas to address all the complexities, sustainability offers. Suggested ways forward linked with the methodology taught during the workshop has to do with the framework/templates provided for the 5-step methodology and had an overwhelming success. This methodology helps to tackle complexity by providing a clear step to include problem statement, identification of stakeholders' concerns, a step, focusing on factual information regarding the former, and sustainability assessment and reflection parts. At the workshop, several participants mentioned that sustainability-focused new courses are being set-up at their respective departments and the topic is addressed at the top level at universities, including setting-up responsible personnel/new responsibility areas.

Specific comments from a staff member of a mechanical engineering faculty suggested the need to have a more specific course focusing on sustainable development, apart from existing specialised e.g. “ocean engineering”, “green materials”. Among the essential courses not being taught, were suggested: “Lifecycle Analysis”, “Materials Selection”, “Critical materials”, “Project management”, “Science Communication in Engineering”, “Materials Engineering”, “Materials Science & Technology”, “Sustainability & Social Impact”, “Waste Management”, and a need for more “Arts/Humanities – related subjects”.

3.2 Discussion

The preliminary findings from piloting our survey in the workshop advocate for the need to establish the baseline of what is practiced in Universities at the curricular level, but also mandate the need to see sustainability as a WIA. As evident, Universities are trying to develop new courses to tackle sustainability but sometimes these are highly specialised and they do not help students understand the bigger picture of what sustainable development is and develop general sustainability competences. This coupled with the lack of SDGs and climate change education show that crucial areas of tackling sustainability challenges are missing from curricula. However, educators in the workshop showed that when an educational software is combined with a methodology that can help them assess sustainability can be an important way of enhancing learning outcomes for students. In other words the pedagogy and specially designed educational material that accompanies the software are of utmost importance. Still the educators shared generic views such as that sustainability is a priority of their institutions and the University is hiring personnel and developing committees or other strategies to tackle it, and here our survey can clarify the areas that University is aiming to focus on regarding sustainability and help University educators and staff clarify the benefits of a WIA into their sustainability integration.

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In this study we have established the need for the student and staff survey in alignment with our published framework as it will provide the data needed to understand how Universities are integrating sustainability and suggest ways forward. The findings of the questionnaires will be triangulated against the results of the previous framework in a new study. The aim is to evaluate the current state of sustainability integration at science and engineering focused universities/faculties, offering ways to address any gaps and to offer recommendations for technology companies to promote sustainability through their education offerings. The alignment of perspectives among staff, students, technology companies' contribution to sustainability, and our framework will be checked after final data analysis and ultimately will suggest practical steps to address sustainability awareness, educational and WIA implementation gaps.

4 SUMMARY AND ACKNOWLEDGMENTS

This paper describes the second stage of the research project, focusing on the two questionnaires for university students and educators based on the framework, which brings together UN Sustainable Development Goals and Learning Outcomes in Higher Education (published elsewhere, e.g. Vakhitova et al. 2023).

The questionnaires focus on assessing sustainability awareness and involvement of staff and students of Science and Engineering Departments in sustainability activities, using a Whole Institution Approach. The preliminary results were collected, using a part of the questionnaire for educators, and described in this manuscript. Among the main findings is that implementation of sustainability into the curriculum to tackle global sustainability challenges needs to be further improved, and this is the main goal of the third part of our effort.

We would like to thank the participants of the workshop in Cambridge (UK) for contributing to this project.

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Centering Meaning-Filled Design Within Engineering Education:
Recommendations on how to integrate interdisciplinary architectural design charrettes, community engagement, sustainability principles, and adapted Agile methodologies into a student-centered, project-based engineering program

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Abstract
The Liberal Arts and Engineering Studies program (LAES) is a hybrid engineering and humanities degree housed in both the engineering and liberal arts colleges. LAES requires the same required math and science courses of standard engineering degrees, adding upper-level concentrations split equally between advanced engineering and humanities courses.

LAES was designed for retaining and recruiting a diversity of students in engineering, and to address recent innovations in industrial practice, technology design, and community-centered education. Through fifteen years of trial and error, the LAES program has developed a set of meaning-filled design guidelines for project work, combining engineering and humanistic problem solving with sustainable environmental practice integrated throughout every aspect of design, production, and use. In partnership with many departments across campus, especially Cal Poly's architecture program, LAES has worked on many projects that exist within the complex economic, political, social, spatial, and cultural needs of local communities.

LAES projects in collaboration with architecture students, have ranged from community housing construction with re-purposed shipping containers, to re-designing pedestrian neighborhood corridors, to the use of narrative-driven STEM education modules with underserved middle school students, to the design of immersive-reality explorations of artificial coral ecologies off the coast of California.

In this paper, we review what we have learned from our project work, with a focus on student learning assessment, leadership training, working across disciplines, and teamwork management, demonstrating how those practical academic concerns interact with the instruction of our design principles. We conclude by offering practical

recommendations for how other programs may use some of our design guidelines and project ideas within their own curriculums.

1 INTRODUCTION

1.1 Section 1 **University & Program Context**

The Liberal Arts and Engineering Studies degree at the California Polytechnic State University (Cal Poly) in San Luis Obispo is a hybrid BS program combining the study of engineering with the study of the arts and humanities. The program encourages students to see engineering, the sciences, and humanistic study as interconnected and as equally necessary for solving our planet's most important problems. LAES has the same entrance requirements as the College of Engineering at Cal Poly, thus requiring a strong grounding in physics and math, as well as the same writing, communications, history, culture, ethics, and reasoning requirements of the most demanding degrees in the College of Liberal Arts.

Based on continual student input and faculty guidance, the LAES Program has developed a number of popular hybrid concentrations that intermix engineering and liberal arts to create specializations in the study of sound and electronics; theater arts and computer game design; psychology and computer system development; art and aesthetics with industrial design; environmental stewardship with power systems management; community development with project design principles; and computer programming with technical communications. The LAES degree allows students to combine the most challenging aspects of the Colleges of Engineering and Liberal Arts at Cal Poly, while creating a hybrid study program that prepares them for their chosen career.

The LAES curriculum allows students to participate in multi-disciplinary development teams that work on real-world national and international technology and culture projects. To foster high-level leadership and communication skills, LAES student projects are always run in collaboration with other Cal Poly majors from Engineering, Liberal Arts, Architecture, and the Sciences, while working one-one-one with our program's commercial clients and partners from California and overseas. To further prepare students for the global marketplace and provide them with intercultural communication skills, the program strongly encourages students to spend at least one quarter studying or working abroad (LAES provides credit and partial funding for these trips).

LAES graduates have been highly successful in obtaining technical, design, and management careers in companies such as Warner Brothers Studios, Disney, Sony Pictures, Tesla, Apple, DTS, Universal Studios, Microsoft, as well as a wide range of high-tech and creative design companies throughout the world. The LAES degree has also served as the foundation for alumni who are currently pursuing graduate studies in MA, MS and PhD programs in psychology, engineering, social sciences, education, law, and business management.

1.2 Section 2 **Addressing Loss of Engineering Students**

The LAES program began as an attempt to stem the flow of Cal Poly students leaving the engineering college mid-way through their studies. At the time, well over 30% of the students who entered engineering as freshmen were changing to majors in the colleges of business, liberal arts, or science and math. Many of these dissatisfied engineering students chose to leave Cal Poly altogether, seeking engineering degrees at institutions that were less restrictive or in some way allowed for more productive integration with coursework from other disciplines. Engineering students who did not have the resources to start again at another institution or who could not afford to spend an additional two to three years to complete a new degree at Cal Poly decided to stay in engineering, resulting in lower grades, and overall dissatisfaction with the institution.

After a year-long, multi-level university proposal review process, the pilot LAES program was fully adopted into the Cal Poly curriculum as a BA program in 2013. The program continued to expand its number of students, roughly doubling in size between 2013-2018 (from 25 to 80 students). In 2017, in response to persistent student requests and requests from the employers of LAES graduates, the program changed from a BA to a BS degree to more properly represent the extensive scientific and technical aspects of this hybrid degree.

The creation of the LAES program, more cross-program collaboration between engineering programs, and a related, open-structure revision to the General Engineering program have often been credited with greatly reducing this loss in Engineering students at Cal Poly. In this paper, we examine some of the key features of the LAES program's design that we believe are central to helping retain and improve the overall academic and professional success of good, interdisciplinary Engineering students, while also adding a more community-focused, principle-driven aspect to Engineering study and practice. The full history of the program's development, along with a discussion of the organizational and divisional differences that had to be overcome the creation of this kind of hybrid program between two different colleges, can be found in this article:

'When the hurly-burly's done, of battles lost and won: How a Hybrid Program of Study Emerged from the Toil & Trouble of Stirring Liberal Arts into an Engineering Cauldron at a Public Polytechnic," Engineering Studies, 2014.

1.3 Section 2 **Project-Based Learning Trial, Error, Assessment & Review**

During the first few years of the LAES program's trial run, all the faculty, administrators, and students connected to the program engaged in much trial and error to determine the most effective methods for bringing together students with diverse LAES academic concentrations to work complex projects that needed to produce a set of useful deliverables for real-world clients. At the same time, the LAES program was also experimenting with how to partner with other academic programs for short- and long-term engagements on the same project, with design and development work that often spanned many quarters.

Throughout this process the program conducted many informal and formal assessment processes that ranged from student consultations and surveys on group work management and grading, to end-of-process review of project deliverables with project clients and LAES program academic advisors, to examining how some end products fell short of expectations and where others met expectations and goals or greatly exceeded them. These assessments all resulted in action items that were then integrated back into the program the following year to serve as additional points for continuing, long-range review, revision, and implementation.

Over the last ten years, these ongoing assessment processes have informed continual changes (large and small) in the program's core course structures, the selection of each year's project partners, the effective management of student teamwork, and the continual refinement of the grading process. The yearly internal (Cal Poly and CSU) assessment processes were then reviewed and amplified further as the program moved from the trial-run phase to full program phase as a BA, then through a comprehensive series of external reviews, and yet one more program review for the conversion of the program into a BS degree.

These three additional external program reviews (trial-run, BA, BS) involved analysis of changes in student demographics, academic achievements, writing assessment based on randomly selected student senior project essays and documents, student and project client surveys, surveys of potential and actual student employers, alumni surveys, and continual consultation with LAES student leaders to help develop new study concentrations for the degree. The external program reviews were conducted by program directors and academic administrators from other engineering programs around the country including the Massachusetts Institute of Technology (MIT), the Colorado School of Mines, Rensselaer Polytechnic Institute (RPI), Union College, among others.

All the review and assessment processes commented on the program's successful integration of community and client-center projects, charrette-inspired iterative design, and structure for our projects, and the effective use of agile and scrum methodologies in the management of our project-based learning capstone courses and for project/client work. Additionally, over the last ten years of the program's existence, we have integrated a few basic environmental sustainability principles into every project we undertake and have developed program specific meaning-filled design principles. We will now briefly discuss how we put these methodologies and principles to use with three projects chosen from the beginning, middle and current state of the program.

One of our main sources for pedagogical inspiration comes from Schon's work, "Educating the Reflective Practitioner" (1987) in which he says:

"Designing, both in its narrower architectural sense and in the broader sense in which all professional practice is *design-like*, must be learned by doing. Though students may learn about designing from lectures or readings, there is a substantial component of design competence—indeed at the heart of it—that they cannot learn in this way. A *design-like* practice is learnable but it is not teachable by classroom methods. And when students are helped to learn design, the interventions most useful to them are more like coaching than teaching—as in a reflective practicum."

Schon continues by noting that "…professional education should be centered on enhancing the practitioner's ability for "reflection-in- action"—that is, learning by doing and developing the ability for continued learning and problem solving throughout the professional's career. If knowledge in the professions is advanced through this process of reflective practice, successful education of students learning the profession should be centered around opportunities to solve real problems involving multiple approaches and to repeat the process of trial, critique, and reflection often." (Schon 1991)

2 METHODOLOGY

2.1 Section 1 **Community & Client-centered Projects**

Over the ten-year span of the LAES program, we have worked on well over forty different projects, large and small, some running only a few months, others running for many years. These projects are all quite different from each other, often with very different clients and deliverables. However, they all share the same organizational, design and implementation principles.

We have chosen three projects to use as examples in this paper, all of which have and additional shared element of collaboration with the architecture program students and faculty at Cal Poly. These projects also are all centered around community education and civic engagement.

The **HO:ME** project (Housing Opportunities Through Modular Environments; 2009-2010) was a LAES design and development project in collaboration with the Cal Poly Architecture program, and the Housing Authority of San Luis Obispo (SLO). The project worked to design and then have approved for development, a transitional housing facility for the city of San Luis Obispo, built from repurposed shipping container materials, to assist residents transitioning from an unhoused situation into community supported housing situations managed by the SLO housing authority.

The **Two-Towns** project (2015-2017) was a LAES design, development, and user-testing project in collaboration with the Cal Poly Architecture program and various civic and business organizations for the city of Sacramento. This project worked to design, develop, and then test the efficacy of various ways to encourage more public use of a large pedestrian passageway connecting an older commercial part of downtown Sacramento with a newer entertainment complex. The project eventually focused on the use of augmented reality systems to help visitors explore and better understand the artwork and historical displays installed throughout the length of the passageway, thereby also learning more about the history of the structures, land, and communities of California's capital.

The **Ocean Sight One** project (2022-Ongoing) is a LAES design, development, and public education project in collaboration with the Cal Poly Architecture and Music programs and a marine research center at the University of California Santa Barbara (UCSB). This project is developing new forms of immersive visual and aural presentation to take citizens of California into the vibrant artificial coral reefs that have developed at the base of the oil rigs off the coast of Santa Barbara. These rigs are soon due to be decommissioned and, in some fashion, removed. The marine life at their base constitutes some of the most healthy and robust coral environments in the world, environments that many people want to preserve and expand upon.

Ocean Sight One aims to educate the California public about the history of these oil rigs, the complexities of the decommissioning process, the state's connection to this process, the importance of maintaining healthy coral reefs, and the inter-connections between the natural elements of these reefs and the built environments of the rigs which were created for industrial use. The project will develop, test, and then present in various public formats immersive 3D cinematic experiences, mobile virtual-reality, and augmented-reality interactive games, all built from underwater 360 high-quality video and audio captured from deep ocean dives around one of the central Santa Barbara oil rigs engaged in this process.

2.2 Section 2 **Charrette-inspired Iterative Design & Whole-Systems Thinking**

The use of the term word Charette is said to originate from the École des Beaux Arts in Paris during the 19th century, in which instructors circulated a cart (a "Charrette") through the studio, collecting final drawings while students frantically put finishing touches on their work. The work was quickly critiqued, and the process began again building from the positive elements of the most recent critique. A variation of this charrette form of rapid iterative design has long been a key part of Architecture practice and education, but in the last twenty years charrettes have become a part of many design disciplines. We have adopted the use of charrettes to initiate the work on many of our projects in LAES, especially when those projects connect to the Architecture program.

The iterative design methods and compressed design/review/revision structure guides all our work in the LAES program. For example, in collaboration with the Architecture program, for the Two Towns project we used a series of design charrettes with students and local community to develop the visual, interactive, and rhetorical approaches we would take with our design work for the city of Sacramento. The charrette briefs distributed to student teams at the start of the charrette required that all the charrette's design iterations (in accordance with the federal building guidelines from the Americans with Disabilities Act—ADA) account for accessibility issues in their designs (designing for visitor differences with hearing and seeing abilities, height, wheelchair use, language, and age).

This design requirement to account for public accessibility has become a central requirement for all LAES projects, teaching students to empathize with how different people and communities will engage with the technologies and systems they create. In their accounting for ADA guidelines in all their work, engineering students must also research, discus and resolve in their final design issues of inclusion, diversity, equity, ethics, psychology, and civic governance alongside their concerns for safety, efficiency, and effective use of materials.

We have found that this whole-systems form of thinking requires the LAES students to make active use of their studies in liberal arts as much as their study in engineering and the sciences. This inter-linkages of concepts between disciplines through hands-on practice and team-centered discussion, we believe forms the core educational purpose of our de-centered capstone courses in which students teach themselves as much (if not more than) the program and our faculty teach them. (Muscatine 2009)

2.3 Section 3 **Agile & Scrum Production Methodology**

Agile is a methodology for software development that emphasizes flexibility and collaboration between cross-functional teams. (Beck et all 2022) It emphasizes iterative development, continuous feedback, and adapting to changes as they arise. Scrum is a specific framework for implementing Agile principle and values in product development. (Sutherland 2015) It defines specific roles, events, and artifacts that help teams work together efficiently and effectively. It involves a series of sprints, lasting two weeks each in our courses, during which the team focuses on a particular set of features or functionality deemed most important to the customer to grow the working product increment in a way that maximizes the return on investment. At the end of each sprint, the team presents its completed and tested work to all stakeholders who collectively decide which work items to keep, change, or remove. This activity is called a Sprint Review.

Our students use Scrum to complete work for our collaborators. Scrum keeps the student teams communicating and working together effectively while remaining consistently focused on customer satisfaction. The testing requirement of the Sprint Review improves the quality of student deliverables while its live demonstration of working functionality component drives customer feedback and involvement. The scope of work completed, thoroughness of testing, presentation quality, and rate the stakeholders approve of work provide regular opportunities for individual and team learning assessment to guide our course grading.

2.4 Section 4 **Project Integration of Environmental Sustainability Principles**

Many of our projects in LAES are not lavishly funded, and often function with almost no funding at all. Therefore, from necessity, the program focuses on frugality and recycling. As a result, the program has adopted a cradle-to-grave-to-cradle principle for all project purchasing and equipment use. But we also require students to demonstrate how they have used the cradle-to-grave-to-cradle principle with their project designs and recommendations for future iterations of their project solutions.

The overall goal of focusing on continual re-use and re-creation with our project and design materials is to, whenever possible, divert our materials from becoming an immediate addition to the waste stream of the community. This was demonstrated in the HO:ME project by the very nature of the materials we were proposing to be used for the city's housing project—shipping containers which have become a blight for many countries where they are discarded into vast waste dumps once they are deemed no longer viable for use in containerized shipping.

HO:ME project students worked with the city of San Luis Obispo, to convince the local community that these re-purposed containers of steel and wood could provide effective, aesthetically complimentary material for construction at a much lower cost than working with less sustainably sourced building materials. Two Towns project made use of existing artwork and informational materials in the passageway, and a connection with the smartphones of visitors to not only create newly expressive and interactive "materials" for the space, but also to educate visitors about the history of these artists who created the work (the Royal Chicano Airforce). These artists designed their work to function at two levels: one level had a hidden cultural history embedded within each mural which was accessible to those who knew of the artists intention and symbology prior to viewing, and a second level designed to teach all visitors about the agricultural practices and migrant labor communities connected to the city of Sacramento.

While the Ocean Sight One project is still in early process, the entire focus of the project is on large-scale sustainability issues that involve the preservation of robust marine environments that are intimately connected with the repurposing of industrial construction and drilling materials. The media aspects of the project also work to make extensive use of prior-gathered site images, sound recordings, and site data for presentation in a new format designed to instruct larger state audiences about the sustainability decisions the state will be making on their behalf in the coming years.

2.5 Section 5 **Project & Program Integration of Meaning-Filled Design Principles**

As a result of ten years of work with charrettes and agile, in conjunction with creating products and solutions for different clients and communities we have arrived at a set of design principles that we call meaning-filled design. We require all students to address these principles, in some substantial way, with every part of work on an Agile development team, with their collaborative work in a charrette process, and with the development of their individual senior projects.

These design principles evolved from the actual construction and implementation of our projects in actual public locations, through interaction with visitors, audience members, and other people in a community. Actual use, by humans, of our design decisions in human communities immediately **gives meaning** to our project deliverables, inventions, and overall solutions, with all the complexities (ethical, moral, symbolic, communicative) that come with this use-generated semiosis. Therefore, when working in community-centered contexts, our students can not only design for technological and mechanical efficiency and effectiveness but must also design for **human-centered meaning** that arises from use. We say their work is meaning-filled, in that they are aware that through public use, every aspect of what they create will be invested with meaning as it enters its use community, therefore it is meaning filled.

These meaning-filled principles, at one time or another, serve as the basis for nearly all our program review processes and are key points for discussion with senior students as they develop their senior project, capstone projects.

These design principles are:

1) **Build for and with community**, appreciating and integrating local symbols, signs, stories, and history into your work.
2) **Extend empathy** throughout design by understanding and accommodating difference.
3) **Encourage critique** through open collaboration and iterative participatory revision.
4) **Embrace complexity** while working toward simplicity.
5) **Establish trust and transparency** through extensive user testing and critical engagement.
6) **Be inclusive** in all discussions, designs, implementations, and public use.

A full discussion of these design principles and their application in our program would require a much longer paper to cover in depth. We introduce these principles here for consideration by other engineering programs that may be asked to become more community-focused and inclusive in their pedagogy but lack curricular methods to address these concerns within a more traditional engineering curriculum.

Instead of trying to address these issues by simply requiring engineering students to take a course in ethics, or community development from other disciplines, we recommend that choosing community-based projects as the center-pieces of problem solving and design within a project-based learning engineering course, can be a way to bring to the fore concerns for empathy, inclusion, diversity, difference and communication while at the same time putting to use standard engineering problem solving for the technological and mechanical aspects of the solution. (Sneider and Zhu 2020)

The three projects referenced above (HO:ME, Two Towns, Ocean Sight One), required engineering expertise and problem solving to be effective, but that engineering work could not stand separate from the equally compelling liberal arts concerns dealing effectively and fairly with community histories, needs, and interests.

3 RESULTS

3.1 Section 1 **Adapting to Diverse Student Needs & Diverse Demographics**

Diverse projects working with diverse communities provide a diverse collection of students many ways to personally connect with the work at hand and allows them to connect what they are producing as students and learners with their lived experiences from outside academia and their roles as citizens in a global community. We believe the program’s focus on diversity in every aspect of design, instruction, and community engagement has made the program welcoming to students who may have otherwise felt their full set of interests and lived experiences were not considered relevant within an otherwise more traditional, fundamentals-only engineering curriculum. (Lehr and Haungs 2015)

When surveyed over the years, by external program reviewers and through internal program assessments, current and recently graduated students comment on how the integration of engineering and humanities disciplines made them better communicators, collaborators, and more active members of their community. These findings were summarized, in one external program assessment (2012) by the lead reviewer from MIT who noted:

"Our site visit…made it clear that student retention at Cal Poly was one of the most admirable achievements of the LAES program. LAES currently serves as a "retention net" (as distinct from a "safety net") in serving to retain some of the brightest, creative, self-driven and entrepreneurially minded students who were formerly enrolled in an engineering degree program at Cal Poly…it should be noted that the program contributes not only to the general problem of retention, but to the specific problem of retaining women, minorities, and socioeconomically disadvantaged (and as it turns out, privileged) students who feel overly constrained by a traditional engineering degree program…(surveyed students) reported a separate passion, for music, for computer graphics, for law, for global economic development—areas of study that maps onto the disciplinary mix generally found within the College of Liberal Arts."

3.2 Section 2 **Learning Assessment Using Agile Adapted to an Educational Setting**

The events and artifacts defined by the Scrum framework provide natural points in production to integrate academic grading, specifically Sprint Reviews. This has two main advantages: grading efficiency and increased student engagement. The grading process is more efficient because there is no need to introduce extraneous artifacts such as quizzes, exams, or written reports. We use a grading rubric that measures the following criteria of a Sprint Review: scope of completed work, work items accepted, testing, demonstration, professionalism, individual review, and publishing materials. The use of Sprint Reviews not only provides a consistent method to incorporate stakeholder feedback it also provides consistent feedback to each student regarding course performance.

The Scrum framework also increases student engagement. At the beginning of each Sprint, each team is empowered to select the scope of work they will complete during the sprint. They make these choices considering the skillsets of the team, available resources, and stakeholder requirements. This gives them direct influence over their own learning assessment while providing real world services to community partners. Our use of Scrum fits naturally into any course that strives to focus on project-based learning, such as in a cornerstone, capstone, or senior project experience. Scrum seamlessly provides team management, a clear production schedule, customer feedback, and opportunities for academic assessment that is widely used in industry.

Summary

While building a hybrid engineering and liberal arts program like LAES might not be possible at other institutions due to structural, political, and disciplinary impediments (Vanasupa et all 2012), we believe that many of the design and instructional principles we have developed and refined over the years can be adopted in piecemeal to help diversify, strengthen, and positively amplify attempts to better connect engineering education with the communities of students and civic/commercial organizations that it serves.

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THE EFFECT OF CAMPUS PRAKTIKUM ON THE CHOICE OF UNIVERSITY STUDIES

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ABSTRACT

In some Spanish universities in recent years, there has been a decrease in the number of students, mainly due to the drop in the birth rate and the increase in the number of universities throughout the country. In addition, the number of (unknown)bachelor's degrees that can be studied at university has also increased.

For these reasons, since 2010, an activity called Campus Praktikum has been carried out at the Universitat Politècnica de València to bring the university studies taught at this centre closer to secondary school students. The aim is to show the studies taught at the UPV (mainly engineering studies), to find out about the professions linked to these studies and to be able to have testimonials from university students who are currently studying. During one week, secondary school students take part in

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workshops related to university studies, which give them an in-depth understanding of the content of their studies and university life.
The main objective is to increase the number of students in general and, above all, to increase the number of women who choose the UPV for their university studies.
The paper describes what the activities of the Campus Praktikum consist of and compares the opinions obtained through surveys of students who enjoyed the activity right after finishing the campus and the information obtained from the student's registration at the university.
With all this information conclusion will be drawn, analysing the actual effect of this type of activity on the student's choice of university studies.

1 INTRODUCTION

Over time, the number of universities in Spain has increased significantly. When the Universitat Politècnica de València (UPV) was established in 1968, there were only 18 universities in Spain. By 1990, that number had grown to 40, and as of the 2020-21 academic year, there are now 84 universities in Spain, with 50 of them being public and 34 private (Ministerio de Universidades, 2022), (Rodriguez, 2017).

This rapid growth in the number of universities has led to diverse academic programs and study locations, creating a competitive environment for universities. To attract the best students, universities must take action to publicize their programs and campuses. To address this challenge, the UPV launched the Praktikum Campus in June 2010, initially as a pilot experience at the Higher Technical School of Industrial Engineering. The program has since expanded to include all schools, faculties, and campuses of the UPV.

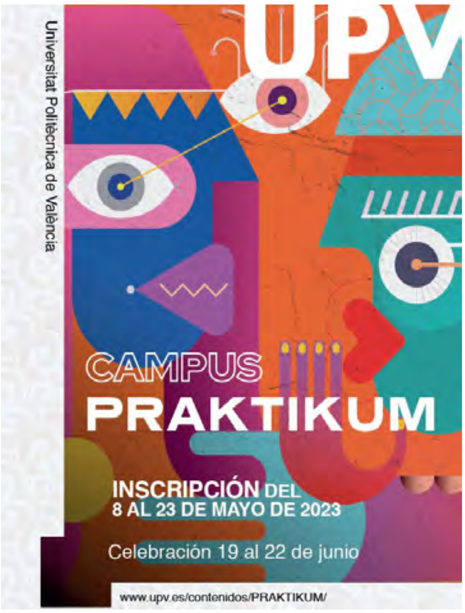

Fig. 1. Image and poster of Campus Praktikum 2023

The Praktikum Campus is designed for high-performing students in their first year of the Baccalaureate or Higher Degree Format Cycle (in Spain, young people finish compulsory education at the age of 16. Subsequently, students who wish to pursue university studies take the baccalaureate, which consists of two preparatory courses for university entrance). Participants can attend workshops and activities organized by UPV teachers and researchers and experience campus life first-hand.

The Campus Praktikum aims to promote different degrees offered by the UPV, attracting students and making the university their choice for higher education. The paper describes the selection process, workshop assignments, and preferences based on gender.

Additionally, it explores the different activities during the week-long Praktikum Campus and the feedback gathered from participants.

At the time of writing, registration for the Campus Praktikum 2023 is open (Figure 1).

2 METHODOLOGY

2.1 Which students can participate

The methodology section of this paper outlines the various aspects considered in developing Campus Praktikum 2022. The Praktikum Campus programme has grown from a single school and project in 2010 to 33 projects in 2022 across 11 schools and two faculties. The projects that will be part of the Praktikum Campus will be published on the UPV website[2] in May, and the opening of registration for first-year baccalaureate or vocational training cycle students will be publicised. Secondary education institutes and training cycles are also contacted via email, explaining the Campus and encouraging centres to invite the best students.

To partake in the program, both the student and their high school must take note of the following recommendations and requirements:

Student Requirements ; To be admitted, the student must:

- Be in their first year of a baccalaureate or vocational training cycle during the 2021-2022 school year.
- Have completed all areas and subjects during the school year.
- Provide an academic certificate from their high school that displays their average for the first and second terms.
- Participate actively in various activities at the Campus Praktikum 2022 UPV. (It is anticipated that this will require approximately 25 hours spent at UPV.)
- Complete the evaluation and satisfaction surveys after the program.

Recommendations for the student's school include:

- Each high school should disseminate information about Praktikum, taking into account the minimum average grade required for admission to the Campus in previous editions.
- Please keep in mind that for the Praktikum 2022 program, three students from the same Center will be chosen. However, any number of candidates may apply as appropriate.

Students who wish to join campus activities should indicate which projects they would like to participate in, ranked in order of preference, and provide a certificate of their grades from the first and second evaluations. Selection for the program will be determined by both grades and project preferences.

2.2 Description of Campus Praktikum activities

Throughout the week of the Praktikum Campus celebration in 2022, high school students were present at one of the UPV campuses (Vera, Gandía, and Alcoy) from 9:15 am to 5:00 pm, engaging in various morning and afternoon activities as detailed in figure 2's schedule.

The aim was not only to introduce students to the degrees offered at UPV but also to expose them to the broader university experience. In total, 33 projects were available during this year's call, linked to 40 degrees across the three UPV campuses, as seen in figure 3's list of projects.

The workshops, primarily in labs, encouraged hands-on learning, with UPV faculty and staff providing activity proposals (Figure 4). At 2.00 pm, students took lunch breaks and could ask questions and receive information from current UPV students.

[2] https://www.upv.es/contenidos/praktikum/

Monday 20th June	Tuesday 21st June
8:30 a 9:30 Pick up of credentials (Auditorium) 9:30-10:00 Presentation of Campus Praktikum 10:30-13:45 Workshops in the Faculties and Schools 14:00-15:30 Lunch and break 15:45-17:00 Sports, Factory Design, and visit UPV	9:15 Arrival at meeting point. 9:30-13:45 Workshops in the Faculties and Schools 14:00-15:30 Lunch and break 15:45-17:00 Sports, Factory Design, and visit UPV
Wednesday 22nd June	**Thursday 23rd June**
9:15 Arrival at meeting point. 9:30-13:45 Workshops in the Faculties and Schools 14:00-15:30 Lunch and break 15:45-17:00 Sports, Factory Design, and visit UPV	9:15 Arrival at meeting point. 9:30-12:30 Workshops in the Faculties and Schools 13:00 Closing of Praktikum 2022 13:30 Aperitif and Goodbye

Fig. 2. Example of a schedule of a student participating in the Praktikum campus 2022

In the afternoons, there were three different types of activities, including a Geocaching activity designed to explore the entire UPV campus, a series of sports activities (Figure 5) highlighting the UPV's sports and activities offerings, and a Factory Design[3] program showcase (Figure 6) in which students from various UPV faculties come together on shared projects.

1. Biotechnology: addressing big needs with small tools
2. Science and technologies for better and safe food
3. Agri-food engineering: from the field to the table
4. Technologies that transform the natural environment
5. Learning to fly
6. Robot design and programming
7. Microelectronics at your service
8. Objects: devising, visualising and manufacturing
9. Engineering high-performance vehicles
10. Living spaces: architecture and design
11. Arquiteknica 2.0 building ingenuity
12. Geopraktikum: your map of the world
13. Informatics for the society of the future
14. Big data: applications to artificial intelligence, cybersecurity and knowledge discovery
15. Robotics and computational thinking
16. Walk with us
17. Tekno-industrialise
18. Energy engineering
19. Chemical engineering
20. Communicating worlds: nanoscience and materiality at the school of telecoms
21. Know how to achieve entrepreneurial success
22. Art and design: practical experiences
23. Art surgery
24. New challenges in tourism
25. Sustainability and the environment
26. The audiovisual world: technology and communication
27. Interactivity and telecommunication
28. Development of materials for electrochemical applications
29. Chemical engineering as an answer to water problems: design of a direct osmosis process
30. Chemical engineering in the elimination of persistent contaminants: design of an adsorption column
31. Technologies transforming the natural environment
32. Recycling and re-use of waste
33. Introduction to chromatography as a method of analysis

Fig. 3. List of projects that can be carried out during the Praktikum Campus.

Fig. 4. Students participating in workshops.

[3] https://generacionespontanea.upv.es/

Fig. 5. Activities organised by the sports area.

Fig. 6. Factory Desing UPV Teams.

3 RESULTS

The Praktikum Campus 2022 was a successful event that fully satisfied all participants, and students were delighted upon completion. To better gauge the extent of satisfaction and identify areas for improvement in the program, 203 students completed an eight-question survey. The questionnaire included inquiries about the campus organization, such as the dates and duration of the event, and questions specifically regarding projects, such as the level of satisfaction (Figure 7) and whether participation influenced their university studies choice (Figure 8).

Fig. 7. Are you satisfied with the project you have been involved in?

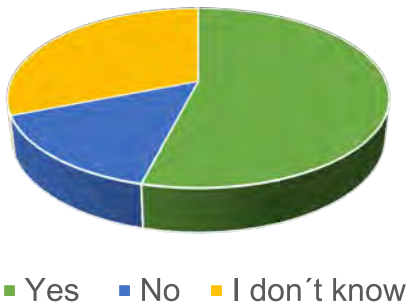

Fig. 8. Do you think your participation in Campus Praktikum will influence your choice of stuides?

Furthermore, a Likert-scale question was posed to get feedback on each student's project (Figure 9). Conversely, the level of participation in the workshops has been inconsistent when viewed through a gender lens. In the highly sought-after 1 Biotechnology workshop, all selected students were female, and the minimum average grade required to participate was 9.5 out of 10. However, in computer science-related workshops 13 and 14, over 90% of selected students identified as male.

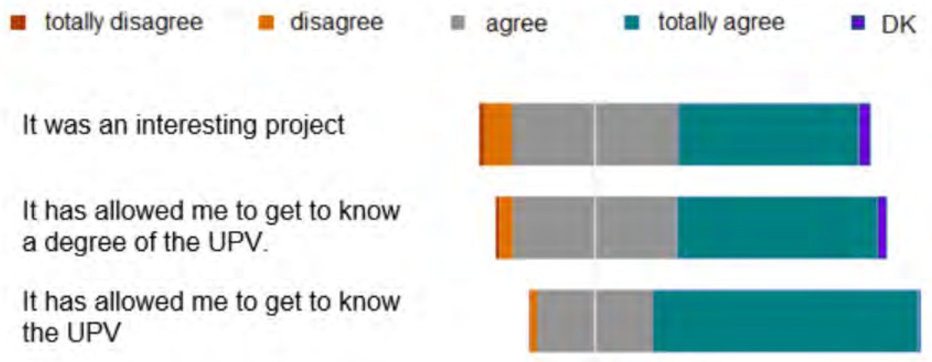

Fig. 9. Students´ opinions about the project they have participated in

This gender trend is also reflected in undergraduate classrooms. Workshops 1, 10, 22, and 23 had the most female-identifying students, with percentages ranging from 100% in Workshop 1 to 65% in Workshop 10. Conversely, most students in the remaining workshops identified as male, with workshops 6, 9, and 15 being exclusively male. In addition, two open-ended questions were posed to students regarding their intended studies and their opinions of the Campus.
A study has also been launched to determine which students participate in the campus praktikum, and who subsequently choose the UPV as the university to do their degrees. Due to the suspension of activity in the 19-20 and 20-21 academic years by COVID, only the students who participated in the Campus Praktikum in the 18-19 academic year began their university studies in the 20-21 academic year could be known. The results (Figure 10) show that 55% of the students chose the UPV. Moreover, there is a great variety in the chosen studies (Figure 11).

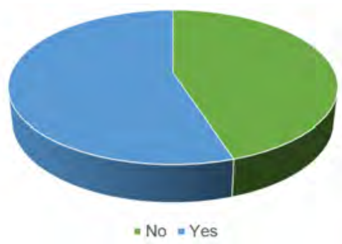

Fig. 10. Students enrolled at the UPV after the Campus Praktikum

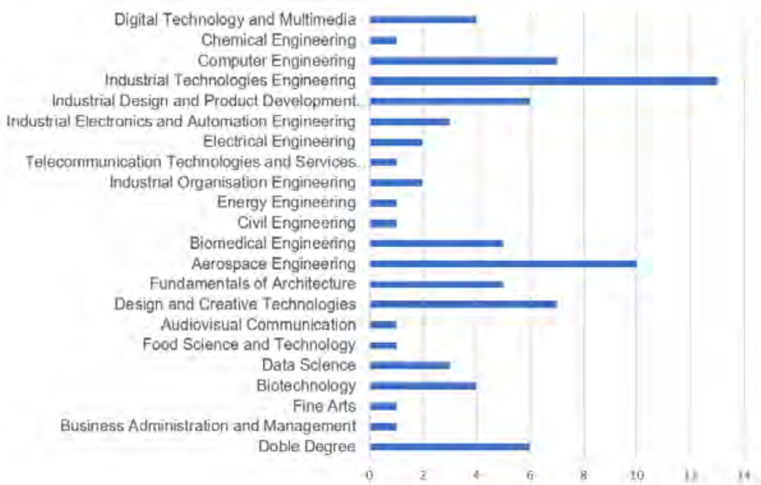

Fig. 11. Studies chosen at the UPV by Campus Praktikum participants

4 SUMMARY AND ACKNOWLEDGMENTS

As a summary of the work it can be said:

- Participation in the Praktikum Campus positively impacts students, and 96% express their total satisfaction with their participation.
- It should be noted that all the personnel involved in the preparation and delivery of the workshops of the projects do so voluntarily, without receiving any financial compensation.
- However, the most remarkable result is that 54% of the participants have indicated that their participation in the Praktikum Campus will influence something as crucial as selecting their university studies. Only 31% indicate that this activity does not affect this decision.
- Primary and secondary schools must continue to work to motivate girls to become interested in STEAM studies. It is essential to show models of women who have followed this type of study and not lose the talent of half of the population, which for some reason, prefers not to follow this type of study.
- It is essential to carry out this type of action to bring universities closer to their future students so that they get to know each other and help them choose the studies that will bring them closer to the professionals they will be in the future.

It is foreseen that in the coming years the activity will continue, and the results will continue to be analysed to optimise its content and ensure that as many students as possible get to know the UPV.

The authors would like to thank everyone involved in the realisation of the Praktikum Campus for their dedication to the project and, above all, the students whose enthusiasm encourages us to continue with the task.

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TOWARDS BUILDING A FRAMEWORK FOR CONTINUING ENGINEERING EDUCATION IN HIGHER EDUCATION INSTITUTIONS: A COMPARATIVE STUDY

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ABSTRACT

Continuing engineering education (CEE) is becoming an attractive notion of continuously enhancing and upgrading the engineering skills required by the Fourth Industrial Revolution. Current developments in science and technology and the challenges to address the United Nations Sustainable Development Goals (UN SDGs) of the 2030 Agenda require updating theoretical knowledge, skills, and specific practical work. Even though higher education institutions (HEIs) can provide CEE or CPD (Continuing Professional Development) within or external to degree programs, CEE focuses on training engineers as lifelong learners to meet societal and industrial needs. A comparative study was conducted among eight universities to analyse the strategies used to provide CEE services at an institutional level. This study aims to investigate approaches and practices in CEE offerings to learn lessons and adjust CEE programs and policies in the HEIs involved in this research. The study followed an adapted version of a Comparative Case Study (CSS) as a suitable framework to map the CEE strategies and approaches of the participating universities. Preliminary results indicated differences in the organisational structures, e.g., traditional courses within existing programs. At the same time, other institutions provide flexible mechanisms such as short courses, modules, or micro-credential activities leading to qualifications. Similarities are found in institutional policies aiming at developing postgraduate programs aligned to industry demands. This study reflects the importance of learning programs as resources provided by HEIs applying a framework for engineering education and the engineers' further professional development.

1 INTRODUCTION

There are many drivers for change in engineering education, such as Industry 4.0, Artificial Intelligence, Digital Transformation, or responding to the Global Grand Challenges, such as the UN Sustainable Development Goals (UNESCO 2021a). Quite rightly, research is focused on how we develop the required competences for emergent engineers through university studies, including a mixture of technical expertise, such as in reconfigurability (Andersen & Rösiö 2021), digital skills and data management (Sharipov et al. 2021) and transversal skills, such as socio-cultural/intercultural competency (Boyadjieva &Ilieva-Trichkova 2023), as well as in leadership, interpersonal skills, ability to work efficiently in teams, managing interdisciplinary teamwork, communication skills and change, amongst others. However, these challenges equally require examination of the developmental needs of practising engineers and engineering educators, so that Continuing Engineering Education (CEE) practices are developed to meet these needs. Therefore, for this study, CEE is considered to be the additional education of a practising engineer or technologist/technician after an initial recognised phase of education, typically an undergraduate degree (Uhomoibhi & Ross 2019).

The area of CEE is comparatively under-researched, and there is a lack of contemporary publications around the practices and models within institutions concerning CEE. It is this gap in the extant literature that this research seeks to address, by comparing the institutional practices of eight Higher Education Institutions (HEIs) in eight different countries. This comparative case study will outline what institutions are doing and how they are approaching this. The objective is to capture how CEE is developed and implemented within differing institutions to determine any similarities and differences with the intention to inform enhancements to institutional policies and practices. Also, the differences among these institutions in the level of CEE offerings and approaches can serve as an inspirational source for others to start developing CEE activities in their own organisations. Moreover, we aim to learn from and inspire each other's developments. Consequently, the research question for this study is 'What are the approaches at institutional level to integrate Continuing Engineering Education policies?' As all institutions offer full, taught postgraduate programmes, this research will focus on other forms of CEE offering.

This paper will first outline the context of CEE in Higher Education, briefly introducing the eight institutions in this study, before detailing the comparative case study methodology adopted for this research. Next, the study offers comparative findings around how CEE is organised and resourced, what do institutions offer as CEE, the level of involvement of industry in what is offered distinctive aspects found in institutions. Finally, we discuss next steps and future directions in this comparative research.

2 CONTEXT OF CONTINUING ENGINEERING EDUCATION IN HIGHER EDUCATION

Continuing Engineering Education is an essential aspect of any professional engineer maintaining the required competences to practice, whether this be to stay current with new emergent technologies, or develop new skills, e.g., around sustainability or in change leadership (International Engineering Alliance 2021). Nowadays, there are a range of learning modalities for engineers to develop such practice - through experiential learning, through non-formal learning or through formal learning, or learning-on-the-job (Lynch and Russell, 2009). Additionally, there is also a diversity of providers, from internal training courses and mentoring, online courses, to training organisations, to courses from Original Equipment Manufacturers and Technology/System Providers', as well as a range of offerings from educational institutions, both further and higher education (UNESCO 2021b). This complementary eco-system of providers enables the required flexibility for individuals and their organisations to organise their CEE offers.

HEIs have played a long-standing role within this CEE landscape, particularly in the provision of postgraduate/Masters qualifications, at the research-teaching and research-praxis nexus. However, the greater diversity of learning options and immediacy of access to some forms of learning, makes it important to examine how HEIs are responding to those demands, and to see if there are similarities and differences between the different forms of HEI: public university, private university, technical universities, commercial (for profit) providers. This research adds insight into how HEIs are organising themselves in response to these needs, as well as highlighting how the different types of courses and how these educational offerings are developed (e.g., driven by market, knowledge sharing by HEI, or in collaboration). As all institutions offer taught postgraduate programmes, then the research will focus on other forms of Continuing Engineering Education offering. The focus on just a sample of HEIs is acknowledged as a limitation of this research.

The eight (8) institutions involved in this research are from eight different countries, seven of whom are European (see authors' institutions above), with examples of CEE offered (Table 1). They represent a range of different HEIs across the forms outlined in the paragraph above, and all engage within a range of CEE activities, whether that be offered internally (to students and staff) or for external provision. The fact that the participating institutions are from different countries provides a breadth of approaches. However, it is acknowledged that the institutions are not necessarily representative of these countries. Additionally, the institutions also are at different points in the lifecycle of adapting their CEE provision; this research is not focused on evaluating competitive positioning rather to determine if there are shared aspects that are influencing the decisions on policy and practice.

Table 1. Participating Institutions and code use for results below

Institution	**Code**	**Example of CEE provision offered**
Aalborg University www.aau.dk	A	Short courses/modules, Master programs (MBA) eg within Cyber Security and Privacy, Management of Technology, Building physics, Circular economy, Energy efficiency
Aalto University https://www.aaltoee.fi/en	B	E/MBA programs, long and short courses, micro-credentials, modules, customised programs, online programs. Themes from all six Aalto University schools are represented.
TU Berlin www.academy-tu.berlin	C	Degree programs (MBA, MBL, MSc) and short courses in the areas of Data Science, Sustainability, Management & Leadership, Engineering & Mobility

Tecnológico de Monterrey https://tec.mx/en	D	Degree programs (MBA, MBL, MSc) and short courses in the areas of Business Analytics, Cybersecurity, Biotechnology, Data Science, Applied Artificial Intelligence
Glasgow Caledonian University https://www.gcu.ac.uk/study/part-timestudy	E	Short courses, e.g. in Data Analytics & AI Machine Learning; Renewable Energy Technologies; Climate Change & Carbon Management.
Uppsala University - The Faculty of Science and Technology https://www.uu.se/en	F	Short courses in, e.g. Industrial analytics, Sustainable energy transition, Biomaterials, Additive manufacturing in metallic and ceramic materials, Application of augmented reality in industry, Data mining, Statistical machine learning, Self-leadership etc.
EPFL https://www.epfl.ch/education/continuing-education/	G	Degree programs (COS, CAS, DAS, MAS) and short courses around science, technology and engineering (i.e., Data Science, Machine Learning, Supply Chains, Fintech, IOT, Geoengineering, Risk Management, Urbanism, etc.)
TU Eindhoven https://www.tue.nl	H	Short courses on a variety of topics, e.g. mechanical engineering, etc.

3 METHODOLOGY

The nature of the research question is descriptive and exploratory, so is best suited to a qualitative methodology. Specifically, a comparative case study approach has been taken, adapted from Barlett and Vavrus (2017). A purposive sample of institutions was selected to participate in the study with inclusion criteria being that each institution had some involvement in Continuing Engineering Education; this sampling strategy is recognised as a limitation of the paper, but in this exploratory research a purposive sample is appropriate, as the study seeks to identify factors that influence policy and practice around CEE.

Data collection was achieved through each institution completing information against a standardised set of criteria. These criteria were generated based on factors that covered meso (institutional) level and micro-level (programme and course) factors. Meso factors covered: how policies supported CEE; organisational structure; ease of CEE operating within regulations; permitted offerings (type of courses & provision areas); university systems to support; resourcing (staffing) approaches; teaching, learning and assessment methods. Subsequently, each institution summarised the pertinent aspects that related to the research question into a short (one to two page) institutional summary.

An inductive, group analysis of the detailed and summarised institutional cases was conducted to determine shared practices, similar factors influencing policy, practice and decision making, as well as potential differences. The findings of this comparative analysis are presented below.

4 FINDINGS AND DISCUSSIONS

Based on the collective and comparative analysis of the eight cases, then three main aspects were identified: 1) how each institution organised the provision of CEE, including how it resourced such courses; 2) what courses were offered and how did these fit into any flexible qualification provision, and 3) how strongly were the offerings aligned to the needs of the market (including whether the courses were co-designed between a HEI and another organisation).

4.1 Organisational structure and resourcing

Seven of the institutions arrange some (or all) of their CEE offerings from within the institution's existing organisational structure, whereas in one institution (#C – TU Berlin) then this is solely arranged through an associated private company (APC) (Table 2). As an APC is also a form of centralised offering (owned subsidiary of one or more than one institutions), then seven institutions use a centralised approach, reflecting the importance of having strategic vision and policy enactment for CEE, and seeking to use centralised services (such as finance). De-centralised offerings reflect either ad-hoc opportunities, or a decision for continuing education to be more focused in particular schools and faculties. Drivers for different forms of supporting organisational structure relate to national legislation, flexibility, and building from a school/department outwards, with macro factors (legislation, government policy) being a significant driver of institutional policy and decisions.

Table 2. Organisational approach to offering CEE.

	A	B	C	D	E	F	G	H
Associated private company/ foundation		X	X	X	X		X	
Centralised CE offering	X	X	X	X	X		X	X
De-centralised CE offering	X	X				X	X	X

An interesting aspect of CEE between the institutions is differing practices around how these offerings are resourced (Table 3). Six institutions are able to use institutional staff within their existing contracts, but for two institutions (#B – Aalto University, #C – TU Berlin), then they have to remunerate lecturers additionally for their involvement. These two institutions also use APCs, reflecting policy and legal requirements within their institutions/countries. Discussions highlighted that resourcing is a key area of policy and enactment of that policy that enables effective CEE offering.

Table3: how CEE offerings are resourced

	A	B	C	D	E	F	G	H
Institutional staff - within contract	X			X	X	X	X	X
Institutional staff - paid		X	X	X	X	X	X	
External to institution staff - paid	X	X	X		X	X	X	
Partnership with external institution		X		X			X	

Of note, all institutions do not subsidise the running of courses, with the costs being met through a variety of means, including government, commercial or individual funding; the balance of sources of the above funding varies between institutions.

4.2 Types of CEE Offering

All institutions offer full taught postgraduate programmes (as outlined above), so these are not considered in these findings. Table 4 indicates that all partners are engaged in a range of courses – from stand-alone Continuing Professional Development (CPD) modules, to up- and re-skilling, up to full Masters programmes (delivered through APCs, or through credit stacking in a more flexible way). These offerings can be non-credit bearing, or carry credits. For those offerings with credits (for example micro-credentials), then these could be stand-alone or institutions may offer a structure or flexible pathway to a university qualification. Some institutions (#B – Aalto University, #C – TU Berlin) have to clearly distinguish between what their institution offers as Masters degrees and CEE offerings, due to legal frameworks in their respective countries.

Table 4: Types of CEE offering

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Masters (EQF7) programme	X	X	X	X	X		X	
Open course	X	X		X	X	X	X	X
Closed course	X	X	X	X	X	X	X	
Bespoke (*tailor-made*) course	X	X	X	X	X	X	X	X

The majority of the courses offered are to those outside the institutions, such as practising professionals. However, in the discussions (and not reported here) was also the importance of CEE to support staff development, and this is a potential area for future research.

4.3 Engagement with industry and organisations

All institutions have a strong market alignment (Table 5) that demonstrate market awareness and offering relevant qualifications, either through partnership (through co-creation) or through being market-responsive are essential aspects of successful CEE offerings. Additionally, as would be expected within a university, then all institutions offer courses driven from their expertise. Courses are not just for commercial organisations, but are offered for public organisations, and can be commissioned. Amongst institutions co-created courses are still less frequent, reflecting the enhanced co-ordination and co-operation to generate such courses.

Table 5: Market alignment of CEE offerings

	A	B	C	D	E	F	G	H
Market-driven/specified	X	X	X		X	X	X	
University-driven/specified	X	X	X	X	X	X	X	
Co-created	X	X	X	X	X	X	X	X

5 SUMMARY AND FUTURE DIRECTIONS

This comparative study has compared how eight different Higher Education Institutions are approaching Continuing Engineering Education using a comparative case study framework approach. Whilst, the institutions are at various stages of evolution in terms of offering CEE, some have done so for decades, whereas others are newer in this area, then key similarities emerged: broadly a centralised, approach to CEE, with a clear strategic vision that creates clear CEE offerings that are aligned to the marketplace. Differences, such as Associated Private Companies and types of offering and resourcing, emerge often due to macro factors (legislation and government policy). It is clear that these changing drivers are encouraging, or in some cases mandating, an enhanced approach to CEE within institutions, and an approach that is responsive to changing market and societal expectations, that consequently requires a balance between organisational agility and sustaining quality and building on central services.

This initial comparison has highlighted a number of key areas for further research and discussion: 1) what are models to resource CEE offerings, and how can an institution choose the most appropriate option? 2) what are the best practices and models around co-creation of CEE offerings? 3) developing a conceptual framework around developing and implementing a CEE strategy; 4) developing a taxonomy for CEE (as had to be partially done for this research to allow consistency in comparison); 5) What CEE offerings should institutions create for their own staff (to meet changing needs of their profession)? 6) expand this initial exploratory research to survey a wider range of institutions to understand practices, drivers and policies to enable CEE; and 7) What is the role of fixed courses/programmes compared to collecting micro credentials, and how are the micro credentials evaluated (for instance given EQF level)?

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ENHANCING QUALITY TEACHING THROUGH INFORMAL COMMUNITY LEARNING IN KNOWLEDGE CENTRES

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Keywords: *Centres for Teaching and Learning, Learning Communities, Informal learning, Innovative Teaching & Learning Methods*

ABSTRACT

Teaching and learning have always been at the heart of the missions of universities. The growing interest nowadays to pay attention to the quality of higher education teaching results in initiatives such as the establishment of Teaching and Learning Centres (TLCs). The Academy for Learning and Teaching (ALT) at Eindhoven University of Technology (TU/e) has recently been created, and it is still under construction, with the purpose of promoting quality of teaching through engaging staff in interaction and in learning lessons from evidence-based educational practices and innovation in engineering education. Furthermore, ALT supports the professional development of faculty teaching staff through Learning Communities (LCs) as informal learning mechanisms that stimulate knowledge sharing about engineering education experiences across departments (and universities). LCs facilitate interaction with peers, discussions on educational practices, working in

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teams, and exposing academic and education support staff to have access to state-of-the-art research and information on educational issues. LCs are organized by themes, such as Digitalization, that cover topics relevant to innovative practices, e.g., Learning Analytics, Artificial Intelligence in education or Digital Assessment. The purpose of this study is to present the ALT model as a knowledge centre in engineering education that stimulates the advancement of quality teaching. Specifically, we analyze successful factors to constitute Learning Communities, as well as, the motivation of the teaching staff to participate in the LC associated to the TU/e ALT. ALT may serve as an inspiring model for other engineering and technical higher education institutions and universities wishing to promote professional development of teachers.

1 INTRODUCTION

The establishment of Teaching and Learning Centres (TLCs) has arisen in recent years worldwide with the purpose of encouraging better quality of education and teaching, but also to support research in education and innovations (Marbach-Ad et al., 2015). TLCs play an important role in the professional development of faculty, academic teaching staff and educational officers in higher education institutions (Gosling and O'Connor, 2006; Atkins et al., 2017). Research on the value of TLCs points out the benefits to help shaping the professional and academic cultures in addition to instructional practices in the universities (Behling, & Linder, 2017).

Literature on TLCs shows the relevance of setting up linkages and create synergies with institutions' wider communities as well as colleagues at other higher education organizations or TLCs. These linkages make sustainable the purpose of the TLCs, to foster transfer of knowledge and innovations and to promote exchange of activities that can enhance quality of education and teaching.

The outreach capacity of the TLCs aims at targeting not only the primary process of faculty, but also educational staff within a single organization. The functions of the TLCs vary in services and structure being the professional development of teachers; the support to carry out innovations (e.g., the design and implementation of teaching practices); and research in education, the most common activities (Marbach-Ad, et al., 2015).

At the heart of its mission TU/e aims to excel in quality of education and teaching. The three pillars of ALT are the LC as an informal platform for learning, research in innovations in education and the professional development of teachers. In the context of TU/e, innovations within the framework of ALT are meant to support learning from experiments in education, e.g. improving feedback as learning, activating students in large groups, use of technology in education to monitor students' learning, etc. The aim is to research innovations in education to provide evidences and create a culture of bottom-up to quality teaching. Therefore, the establishment of the Academy for Teaching and Learning (ALT) has a crucial role in raising the profile of the university to become an international renowned institution in educational innovation. In establishing ALT, it became important to investigate the factors that constitute an effective knowledge centre, such as:

1. RQ1: What are the successful factors that constitute the organization of Learning Communities (LC)?

2. RQ2: How to encourage teaching staff to actively participate in the Learning Communities?

In the coming sections, the theoretical considerations that frame the construction of ALT are presented. In addition, the methodology and approach to construct ALT is explained. Furthermore, results of the literature review and the participatory consultation are discussed that have given form to ALT. Finally, some reflections/considerations for further establishment of the LC are shared that contribute to further professionalization of the teachers.

2 THEORETICAL CONSIDERATIONS

‘Communities of practice’, ‘learning communities’, ‘collaborative collegial groups’, or ‘networks of professionals’, are oftentimes terms that refer to similar ‘learning structures,’ made up of groups of individuals who share common interests, dilemma’s in educational practices or have a similar goals to improve their practice by interacting regularly with others and engaging in a process of collaborative learning (Wenger, 2006; Wenger, McDermott, and Snyder, 2002).

Theories on education such as situated and contextual learning (Lave and Wenger, 1991), refer to that context and learning should be embedded in a particular social and physical environment. Research shows that involving individuals to share common interests to bring about outcomes, contribute to develop an identity within a community and commitment among disciplinary or interdisciplinary groups. (Handley, Sturdy, Fincham, and Clark, 2006). Research reports about successful experiences of community activities by engaging teachers in problem solving, seeking experience, reusing assets, discussing developments, working together in creating a new curriculum or interdisciplinary courses, and mapping knowledge (Wenger, 2006).

Furthermore, research on the effectiveness of learning communities in promoting advancement of faculty members’ development and in supporting innovation abounds in the literature (Cox, 2001). Harwood et al. (2005) describes the positive experience of faculty members engaged in community seminars to examine their pedagogical practices, as a vehicle to support personal and professional growth as researchers and teachers. Essentially, critical reflection of professionals about what works or does not work are also interesting LCs activities.

Grounded on these theoretical insights, we investigated the characteristics of the learning communities that can lead to a successful implementation. Moreover, we also looked into a model that can stimulate an active participation of the teaching staff in learning communities.

3 METHODOLOGY

The methodology for this study is designed to respond to the research questions (RQs). The methodology consisted of a two-fold approach: (1) Literature review; and, (2) Multi-stakeholders’ consultation.

To answer the RQ (1) *What are the successful factors that constitute the organization of Learning Communities?*, a systematic literature review was conducted. In total 15 journal articles were reviewed. In this study, we only mention the insights of the articles that meet the ALT goals, specifically the focus on LCs. The literature review process followed a systematic approach (Papaioannou, Sutton, and Booth, 2016) of:

- Making a preliminary selection of scientific journals in the field of education, collaborative learning in higher education; professional development; etc.;
- State-of-the-art selection of manuscripts on research on educational practices of learning communities was made within the range of years between 2000 and 2020.
- Search for manuscripts included a classification of words 'communities of practice'; 'learning networks'; 'professional groups in higher education'; 'communities of practices'; 'collaborative learning'; and alike.

To investigate the RQ (2) *How to encourage teaching staff to actively participate in the Learning Communities?,* a stakeholder approach was used consisting of interviews with CTLs, brainstorming sessions and discussions to converge into a model suitable for the context of the TU/e.

3.1 Participants

As a first step to address RQ2, interviews and discussions with staff in national and international CTLs in Europe, Australia and United States of America took place in order to learn from their experiences. Secondly, a Think Tank was organized to brainstorm about the teachers' needs, topics and forms to organize learning communities. Participants were selected by its relevant role in innovations throughout the university. Finally, a consultation and advisory working group was established to converge into a model that may motivate the university teaching staff to actively participate, and eventually, lead a learning community. Table 1 shows the activities and participants involved in this stage.

Table 1. Participants of this study

Participants	Activity
National and international CTLs	Interviews
Think Tank: Program Directors, teachers and education support N=6	Brainstorming about needs, topics and form for LC
Consultation and advisory group (university education management board and ALT management team) N=5	Participatory design of the ALT model

4 RESULTS

4.1 Findings from literature review RQ (1) What are the successful factors that constitute the organization of Learning Communities?

Literature on learning communities in higher education shows the benefits of teachers working in teams, discussing educational practices and engaging in an ongoing cycle of questions that promote deep team learning. Research also points out the successful factors of disseminating innovation results, stimulating interaction and learning from colleagues, as an informal way to contribute to the professional development of academic teaching staff (Sims & Fletcher-Wood. 2021).

Furthermore, engaging teachers in collegial interaction to learn from peers, promoting team teaching activities, supporting co-creation activities and stimulating knowledge sharing in a community are strategies that foster change of culture in an organization and promote institutional-level innovation (Atkins et al., 2017).

Collaboration, sharing knowledge and peer interaction are intrinsic parts of the day-to-day practices of scientific staff and researchers. This way of working nurtures the systemic processes pertaining to a culture of excellence in quality of teaching in universities. Key characteristics from research on factors contributing to successful Learning Communities (LC) refers to (DuFour, 2005; Lutrick & Szabo, 2012):

- **Ownership** of newly acquired knowledge as a sense of empowerment attained as a result of leading a community, organizing meetings, conducting own research projects, etc.
- **Autonomy:** opportunity to select own topics for discussion.
- **Relevance:** topics for discussion are linked to teachers' needs, are relevant for their tasks and aligned to university or departmental strategic vision on education;
- **In-depth:** the value of studying a topic in more depth;
- **Inspiring leadership:** discussions with university/faculty members, being knowledgeable, experience in education and students' learning, acting as a facilitator, etc.
- **Collaboration:** building communities around specific themes is a powerful informal learning mechanism to stimulate collaborative learning among academics as well as to disseminate research. Also, it provides good opportunity to meet on a regular basis with other educators, including their colleagues and the university faculty; interaction; sharing knowledge, etc.
- **Assistance:** to organize and setting up regular meeting times and by keeping the groups focused and moving along.

4.2 Findings from consultation with advisory working group RQ (2) *How to encourage teaching staff to actively participate in the Learning Communities?*

Interviews with national and international CTLs revealed trends in establishing learning communities considering fellows, teaching staff, as an important mechanism to empower academics, but also to foster to professional development. In addition, the construction of these learning niches with a bottom-up approach contributes to a sustainable form to connect people and create networks of knowledge sharing across the university and outside.

Following the findings on successful factors in the construction of CTLs, the ALT model at TU/e, focuses on creating a bottom-up niche, the so-called Learning Communities, for academic as well as for the university educational support staff as a whole, to meet informally, learn and talk about education, the challenges in teaching and learning, in addition to the current developments in innovation in engineering education (See Figure 1).

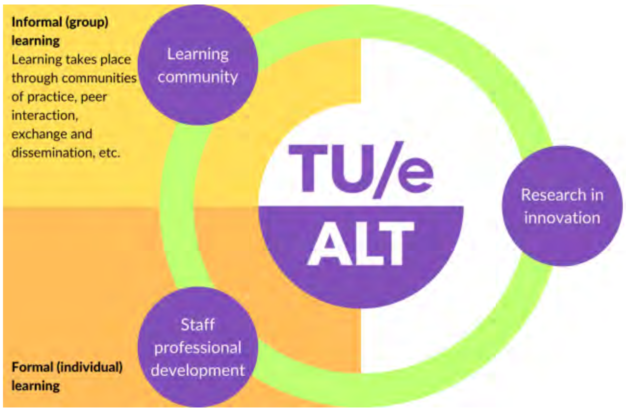

Figure 1. Overview LC informal learning structure.

In the ALT model, a role of fellow is included. Fellows are teaching staff motivated to deepen knowledge in specific educational topics and enhance professional development through educational innovations. Moreover, the approach of selecting fellows, to lead the LCs, follows the rationale to empower teaching staff to develop their vision on education and boost their professional development.. The task of the fellows is to create linkages with departmental academic colleagues, and possibly, across the departments. Fellows lead a thematic LCs and prepare an annual agenda for activities (e.g. get together to solve educational dilemmas, organize seminars, discussions, workshops, webinars with experts/guests from national and international organizations on relevant topics, etc.) and create linkages with national and international LCs. The expected time spent by fellows in ALT activities is at least half a day per week.

ALT learning communities are an interesting opportunity to connect and engage teaching and education staff. Therefore, to realize informal learning in the LC as visualized in the previous figure, the following activities are envisioned (but not limited to) (See Figure 2):

(1) Stimulate consultation, peer interaction and promotes dialogue;
(2) Promote knowledge and experience sharing, information;
(3) Provide mentoring and coaching to (re-)design innovations and put in practices new ideas;
(4) Present research and support in innovations, e.g., how to write an innovation proposal, or how to carry out research on innovation in courses, etc.
(5) Support dissemination of innovations and experiments;
(6) Motivate reflection on vision on education.

Figure 2. LCs opportunities: connecting and stimulating teachers' knowledge sharing

5 CONCLUSIONS

The establishment of ALT is an exciting and challenging undertaking. The benefits of participating in ALT Learning Communities lies in the possibilities to engage in university-wide innovations in education and learn from colleagues from other departments. Opportunities to broaden the scope of practice in innovations in engineering education and to reflect upon results from experiments, lessons learned and research are provided in the round tables, discussions on dilemmas in classroom practices and alike, organized within the LC events.

Moreover, the fact that teachers and education staff from different departments will attend the LC will facilitate the transfer of knowledge and information to own departments contributing, therefore, to stimulate the cross-pollination effect across disciplines, staff and beyond the borders of the departments.

Ultimately, Learning Communities can contribute to promote the quality culture of the organization and nurture the culture of change by participating in enriching and updating the university vision on education with new insights. Leading a Learning Community can also create an impact on teachers' professionalization in education.

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BACHELOR'S THESIS SEMINAR IN COMPUTER SCIENCES AND INFORMATION TECHNOLOGY

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ABSTRACT

A Bachelor's thesis is typically an individually written literature review on a scientifically relevant topic. Additionally, some theses also describe empirical work or report an experiment. Firstly, we introduce how Bachelor's theses are supervised in a joint thesis seminar for Computer Sciences and Information Technology at our university. The thesis seminar is organized three times a year. It consists of six small group meetings led by a supervisor and contains compulsory pre- and post-assignments and active peer discussions. In 2022, there were in total of 187 students participating in the spring, summer and autumn seminars. Secondly, we give an overview of the 98 completed theses. We classify the theses using ACM's Computing Classification System and analyze keywords, the number of references and some other bibliometrics to learn about the students and the potential effects of their different study orientations. We also analyze 14 theses that reported practical work, like the implementation of an algorithm or using existing software tools. The main result of our work is to give a research-based view on the supervision of Bachelor's theses, the organisation of the thesis seminar, and the bibliometrics of the completed thesis.

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1 INTRODUCTION

In 2019 the two universities in Tampere (University of Tampere, and Tampere University of Technology) were merged into Tampere University (Tampere University 2018). The new multidisciplinary university is the second largest in Finland with almost 20,000 students in bachelor's degree and master's degree study programs. The universities had degrees in Computer Science (CS) and Information Technology (IT) with good records of graduates throughout the years. While the separation between the academic fields is profound, and the graduates will still get their diplomas in BSc or BSc in Technology, it is most visible in other than the major field of study, since the degree programmes share most of the software-related studies. Since the merger, teaching has also been harmonised between different cultural and skill backgrounds to cope with the ever-increasing numbers of students, the demands of the pandemic and the pedagogical changes that all these have brought.

In this paper, we focus on Bachelor's theses and the thesis seminar where they are supervised. The thesis is one of the final tasks for the student before graduation, usually in the third or fourth year of study. It would be in the interests of the faculty to get more graduates yearly since part of the funding is based on the number of Bachelor's and Master's degree diplomas awarded, and the funding model emphasizes on-time graduates - those who complete their degree in three academic years.

The aim of our research is to look into the joint thesis seminar to see how well it serves the degree and learning goals of the CS and IT degree programmes. Our research question is:

1. What kind of theses are completed, and do they indicate differences between CS and IT students?

Our analysis is based on the accepted theses available in the public thesis database of the university as well as the enrollment statistics for the 2022 calendar year.

The rest of the paper is structured as follows. In Section 2 we describe the background of the Bachelor's thesis in the computing curricula. In Section 3 we focus on our implementation, its learning outcomes and seminar structure. Section 4 shows the results of our analysis of seminars in 2022. The results are discussed in Section 5 which concludes the paper.

2 Bachelor's thesis in computing curricula

A Bachelor's degree includes either a thesis or a large-scale final project (e.g., a capstone project). In Europe, a thesis seems to be common at universities, and final projects occur more often at universities of applied sciences but this is not a rule. The length of a European Bachelor's degree is three or four years as stated in the Bologna Declaration (European Higher Education Area 1999). In the USA, a capstone project is common instead of a thesis seminar (Blumenthal 2022), especially in the context of industry projects (ACM 2020). The U.S. Bachelor's programmes are mostly four years.

Bachelor's theses are also closely tied to the teaching of research methods, as a properly written thesis contains a literature review that ties the work into existing knowledge in the research area. Koppelman et al. (Koppelman, Dijk, and Hoeven 2011) reported in their case study findings from an undergraduate research course. One of their results was that students feel better prepared to conduct research in graduate programs after the research course. Holz et al. (Holz et al. 2006) point out the large variety of research methods in computing and discuss how they should be taught to students. In our study programs research methods are discussed in the MSc level. However, the literature review approach naturally involves getting familiar with the research methods applied in the literature of one's study field.

2.1 Bachelor's theses in higher education programmes

In Finnish BSc degree programmes, a thesis of a minimum of six and a maximum of ten credits is required by the legislation (Finlex 794/2004 2004). The credits follow the European credit system ECTS (European Commission 2015) where one credit is $26\frac{2}{3}$ hours of student work. Together the seminar and the thesis bring 10 ECTS. The full academic year is 60 credits, and the Bachelor's degree 180 credits in the relevant areas of this paper.

2.2 Bachelor's thesis guidelines

The Bologna process does not specify anything about the Bachelor thesis. Likewise, a thesis is not mentioned in the ACM Computing Curricula 2020 (ACM 2020) though it encompasses BSc programmes in Computer Engineering, Computer Science, Cybersecurity, Information Systems, Information Technology, and Software Engineering. Some earlier computing curricula recommendations by the ACM require a final project, but only the Chinese version of the information technology curriculum includes a graduation thesis (ACM 2017). In computer engineering, one example curriculum mentions a final individual project that includes a thesis (ACM 2016), and in computer science, one example curriculum recommends project courses with a note that a "Reading, Research, or Thesis course" is not enough (ACM 2013).

The only example curriculum containing a Bachelor thesis is the Chinese four-year version of the information technology curricula. It describes the contents of the thesis as follows: "Students do literature translation, literature survey, opening report, system design and development, thesis writing and defending; students acquire scientific research ability, system design and development ability, develop a basis for future work." (ACM 2017) In this respect, the ACM reflects the practices in the USA. However, even if the theses are common in Europe, the Bologna process does not mention a Bachelor-level thesis.

Universities have published local guidelines for bachelor theses, which may be subject-specific or aimed at the whole university. The study guide of Tampere University falls into the latter category. The objectives of the thesis are described as follows.

> With a bachelor's thesis, students demonstrate their ability to apply their acquired knowledge and skills, engage in scientific or artistic thinking and activities and communicate effectively, both orally and in writing, in their mother tongue. Students typically attend a bachelor's thesis seminar while working on their bachelor's thesis. (Tampere University 2019)

3 BSc thesis seminar in computer sciences and information technology

Our paper discusses theses written as a part of a three-year Bachelor's programme at Tampere University. The BSc theses in Computer Sciences and Information Technology are completed by taking a semester-long thesis seminar course. The seminar is arranged three times a year - Autumn, Spring and Summer.

3.1 Learning outcomes

In the seminar, there are two main learning outcomes that are common to students of both degree programs.

1. Learn how to do a small research work with the structure of a common research paper.
2. Learn to write scientific text.

However, the learning outcomes for the Bachelor's thesis in Computer Sciences and in Information Technology are verbalized separately for each in the current curriculum. This is due to the histories of two separate universities, and will undergo further unification for the next curriculum period 2024-2027. Still, when coded together, the core learning outcomes are common for the two degrees both aiming for a completed BSc thesis required in the degree. Together, they include the following. After completing their thesis:

- The student has practised writing a thesis. They know how to design and write a thesis and how to take the academic audience into account.
- The student has experience in searching for and reading scientific and technical papers and writing their results comprehensively. They are able to systematically search for information and recognize the sources relevant to their field. The student knows how to evaluate and utilize sources of information in their thesis and is able to exclude sources not relevant to their work.
- The student has practised interaction with other professionals and knows how to give and receive scientific critique. Their comments are useful and constructive. The student is able to evaluate comments and handle them appropriately.
- The students know how to analyse the key elements of a research problem and their relationships. They understand the nature of the scientific writing process and can apply it in practice.

In the learning outcomes, differences can be identified in the target audience of the thesis. IT highlights the technical engineering audience while CS targets a more holistic professional audience. CS emphasizes the ability to form and defend independent views regarding a research problem while IT takes a more practice-driven approach of verbalizing the learning outcome through the ability to present the student's work and to act as an opponent. CS mentions the ability to address ethical concerns explicitly. IT addresses the ability to take the reader's needs into account.

Between the two degree programs, the main differences in requirements can still be associated with academic writing studies. Whereas students in Information Technology complete an "Academic Writing" module integrated into the seminar, the students in Computer Science have a separate scientific writing course with a scope of 2 ECTS. The reason for such imbalance lies in the differences of the study fields. As the engineering students have natural sciences (mathematics, physics, chemistry) as required studies, their study program is tightly packed into 180 ECTS to match three years of study, and for them, the integration of writing counselling to the seminar itself does not produce credits.

As a form of thesis, a literature review is recommended but constructive research is allowed. In all cases, a thesis is based on a literature review on the topic. Planning and carrying out empirical or constructive research often takes long, thus causing more student workload than expected for the seminar, and possibly lengthening the process of graduation. All students enrol in empirical group projects in their studies to gain practical experience, and in our curricula, these projects are separate from the thesis seminar.

The minimum length of the thesis is 10 pages and it should not exceed 25 pages. It can be written in Finnish or English.

3.2 Thesis evaluation

The theses are evaluated with a five-level grading scale: 1 (sufficient), 2 (satisfactory), 3 (good), 4 (very good) and 5 (excellent). In principle, the thesis might also receive a failed grade, but the supervision process prevents this as the supervisor does not allow the student to make an official submission before the thesis reaches an acceptable level. After the student has submitted the thesis for assessment, the supervisor has 21 days to evaluate the thesis by writing a statement. The statement is then approved by the responsible teacher before it is forwarded to the administration.

The evaluation is based on nine criteria: i) Topic, objectives and thesis title; incl. research question. ii) Structure; structuring the topic and logic of the structure. iii) References; quality, quantity and usefulness, citation practices. iv) Conclusions, achievement of goals and criticality. v) Language, text fluency and appearance (incl. figures and tables). vi) Self-initiative and consideration of feedback. vii) Seminar work activity. viii) Presenting the work and being an opponent in the final seminar meeting. iv) Completing the thesis on schedule. The final grade is not necessarily the average of the criteria, the emphasis depends on the topic, content, and other relevant factors.

3.3 Seminar structure and supervision

Arranging the seminars requires lots of coordination work by a team of responsible teachers who handle general arrangements before, during and after the seminar. Each seminar instance needs to have both students that enrol with initial ideas of their interests and a preliminary topic for the thesis, and supervisors that are experts in the topics chosen by the students. In addition to the content experts, the students also meet with information search experts of our University Library, and Academic Language teachers.

At the start of the seminar, the enrolled students are divided into small groups of 4 to 8 members based on their initial topics. Every small group is led by an experienced teacher or a professor. The groups follow the meeting agendas described in Table 1. The meetings are held two, three or four weeks apart, depending on the phase of the seminar. We have Moodle (Moodle LMS 2023) as our learning management system, hosting both timed discussion forums for the small groups as well as links to shared lecture videos and practical advice on the required tasks.

Table 1: Seminar structure and group meetings

Before the seminar	Enroll, indicate individual interest areas and initial topic.
Group meeting 1	Meet the supervisor and group members. General ideation.
Group meeting 2	Make first mind map, write motivational paragraphs on the topic.
Group meeting 3	Information search with keywords to find articles, make a concept map.
Group meeting 4	Combine the parts into a thesis outline, indicate missing parts.
Group meeting 5	Write missing parts into an almost complete thesis document.
Group meeting 6	Prepare a presentation. Give detailed feedback as an opponent.
After the seminar	Finalize the thesis and submit it.

The full duration of the seminar is roughly four months, and the students are expected to finish their theses within one to six months after the end of the seminar. All theses are checked against plagiarism and stored in the document repository of our university (Tampere University 2023).

The seminar is started by more students than finish it (Table 2). Similarly, the number of completed theses is lower than the number of completed seminars. Partly the low completion rate is due to the administrative delay of several weeks between the submission of the thesis and it becoming available in the document repository. This is why we extended our data collection until the end of January, as indicated in (Table 2).

4 BSc theses in computer sciences and information technology

Our analysis is based on the 98 accepted theses acquired from Trepo (Tampere University 2023). 90 theses were written in Finnish, and 8 theses in English. Most of the theses, 93,

Table 2: Seminars, participants, and completed theses 1.1.2022-31.1.2023.

Start time	Enrolled	Completed seminar	Completed thesis
Spring 2022 seminar	89	65	57
Summer 2022 seminar	32	21	14
Autumn 2022 seminar	66	44	27
Total	187	130	98

are publicly available online, and 5 theses have only abstracts and keywords online. These five theses can be read at the thesis point in the university library.

4.1 Keyword and topic analysis

We categorized the thesis topics using ACM's Computing Classification System (ACM 2012). The ACM CCS is first briefly explained to the students as they start their information search for thesis topics. We have found it a good starting point in search for up-to-date references. The categorization of our thesis sample (98 theses) is shown in Table 3.

Table 3: Theses categorization using ACM's Computing Classification System.

CCS category	IT students	CS students	All
Applied computing	3 (5.2%)	4 (10.0%)	7 (7.1%)
Computing methodologies	4 (6.9%)	5 (12.5%)	9 (9.2%)
Computer systems organisation	5 (8.6%)	0 (0.0%)	5 (5.1%)
Hardware	2 (3.4%)	0 (0.0%)	2 (2.0%)
Human-centered computing	5 (8.6%)	12 (30.0%)	17 (17.3%)
Information systems	10 (17.2%)	2 (5.0%)	12 (12.2%)
Mathematics of computing	0 (0.0%)	0 (0.0%)	0 (0.0%)
Networks	0 (0.0%)	0 (0.0%)	0 (0.0%)
Security and privacy	6 (10.3%)	5 (12.5%)	11 (11.2%)
Social and professional topics	4 (6.9%)	3 (7.5%)	7 (7.1%)
Software and its engineering	14 (24.1%)	7 (17.5%)	21 (21.4%)
Theory of computation	5 (8.6%)	2 (5.0%)	7 (7.1%)
Total	58 (59.2%)	40 (40.8%)	98 (100%)

Mathematics of computing students complete their thesis in a separate seminar with students of mathematics and statistical data analytics. Similarly, students of Networks participate in the BSc thesis seminar in Electrical Engineering (EE). This is due to Networks as a major being common to IT and EE, and as the students are grouped based on their initial topics, it makes sense to keep the Networks students together. Hence these two categories do not have students in our analysis.

The distribution of IT and CS students' thesis topics is in line with the profiles of the degrees with IT being geared toward software engineering, information and computer systems while CS has more of an emphasis on human-technology interaction. Societal aspects and information security are equally present in both. Each student chose up to six keywords to describe their thesis work, and we combined those keywords into loose semantic clusters that are presented in (Table 4) according to their size.

Specific development techniques and tools (such as React, Django, Java, Javascript, C++, Python, ...) often appeared in the keyword lists but were left out of this analysis.

Table 4: Clusters of most common keywords in the theses.

	IT students	CS students	All
1. software engineering, agile, projects	15	7	22
2. machine learning, neural networks	9	6	15
3. algorithms, computation	6	9	15
4. information security, cybercrime	3	11	14
5. programming, web, mobile	4	7	11
6. accessibility	2	9	11
7. data science, data bases	5	5	10
8. usability, user experience	3	6	9
9. social media	3	3	6
10. recommender systems	3	3	6

4.2 Thesis bibliometrics

Thesis bibliometrics for a number of pages, words and references are listed in Table 5. The minimum page length required is 10 and the minimum word count for a thesis to be acceptable is 3000 words. The thesis should have a minimum of 10 references with 15 as the recommended average. The average number of pages in the theses was 18.48. The shortest thesis was 11 pages and the longest was 30 pages. An average CS thesis was 17.6 pages and an average IT thesis was 19.09 pages long. IT students seem to write longer theses as the shortest CS thesis was 11 pages and IT 12 pages, and the longest CS thesis was 24 pages while the longest IT thesis was 30 pages. However, the thesis template in IT renders more pages and thus the number of words gives a better comparison point.

Table 5: Average number of pages, words and references of CS and IT theses.

	Pages (min/ave/max)	Words (min/ave/max)	Ref. (min/ave/max)
CS students	11 / 17.60 / 24	3215 / 4986.74 / 7920	12 / 19.45 / 33
IT students	12 / 19.09 / 30	3105 / 5099.04 / 8303	10 / 18.97 / 44
All	11 / 18.48 / 30	3105 / 5053.15 / 8303	10 / 19.16 / 44

The shortest thesis was 3105 words (IT) and the longest, also in IT, 8303 words. The longest CS thesis was 7920 words. On average the theses were 5053.15 words long. The IT average, 5099.04, was a bit higher than the CS average of 4986.74. However, the differences are not significant.

The average number of references was 19.16 (19.45 in CS, 18.97 in IT). The smallest number of references was in an IT thesis, 10. In CS, the lowest amount of references used was 12. Similarly, the largest number of references was found in an IT thesis, 44 with 33 references respectively in CS. The students are expected to discuss the scientific quality of the studies they write about in the thesis. Our reference counts do not take into account the quality or the publication forums of the references. That kind of analysis might indicate more differences between the student cohorts, the IT students being more oriented towards practice.

4.3 Theses with practical experiments

All the analyzed theses contain a literature review on the topic. There were 14 theses that reported a practical study. These theses can be classified into three main categories (the number of theses in the category is given in the parenthesis):

A) Implementing an algorithm or designing a method or model, or designing a challenging and useful example. (7)

B) Applying existing tools to evaluate something. (3)

C) Collecting data with different methods from different sources and then comparing the collected data. (4)

The seven theses in category A described often an implementation of a commonly known algorithm, like the A* search algorithm or a method to generate random numbers. In most cases, they also contained a small-scale evaluation. Some students published their source codes in a public code repository.

Theses in category B (3 theses) reported applying some existing software tools to experiment, collect and compare data. For example, a student studied accessibility reports generated with WAVE on some web e-commerce sites.

Then there were 4 theses (category C) that reported a comparison based on data that was collected from the literature or from other sources, like websites. For example, in one thesis data was collected using a questionnaire form, and in another thesis, data was collected from GitHub, Stack Overflow and LinkedIn.

5 DISCUSSION AND CONCLUSION

To answer our research question, we did not find significant differences between the CS and IT students' theses.

Minimum requirements have an impact on the overall quality of the thesis. Mostly the students wrote theses exceeding the minimum requirements and the average thesis was along the lines of the recommended, not the minimum. While there are differences in the topics and research methods, having common quality guidelines can be viewed as beneficial.

We sought for causes behind the large number of dropouts (see Table 2). A closer look into the dropout statistics reveals some facts. In 2022, altogether 7 students enrolled twice or even three times in the seminar. From them, only one student has finished the thesis after the second seminar by the time of writing. One reason for this may be that many students in the Computer Science and Computing fields are more qualified in writing Python, C++ or similar code segments than in natural languages. For them, writing the thesis seems difficult and beyond the skills of the student. Similar results pointing out the importance of beliefs of self-efficacy are brought up e.g. in (Blankenstein et al. 2019).

A second cause for discontinuing the seminar is beyond the scope of the seminar itself. Despite our efforts on the seminar arrangements, the thesis is often postponed as far as possible. After graduation most students continue in their Master's degree program and there is no clear cutoff point between the programs. To complicate the matter, Finnish students do not pay study fees in higher education, and they do not see graduation as high on their priority list. Many of them carry out outside jobs to support living or work in an internship to gain experience in the study field, leaving less time to focus on their studies. The national BSc students' survey findings (Education Statistics Finland 2023) for 2022 found that the top three main causes of delays in studies were the lack of motivation to study, health-related reasons and working. The lack of motivation was the leading cause and was on the rise from the previous year. While not directly in the hands of the thesis seminar alone, these aspects are important to take into account and address when planning the seminar.

To wrap up, finding a suitable topic and the motivation to spend time on it to write a thesis requires resilience from the students. A comforting fact is that while thesis writing may take time over the intended time frame, most students eventually get their thesis completed, and the seminars enable effective focusing on thesis writing.

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DIGITAL ETHICS CANVAS: A GUIDE FOR ETHICAL RISK ASSESSMENT AND MITIGATION IN THE DIGITAL DOMAIN

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ABSTRACT

Ethical concerns in the digital domain are growing with the extremely fast evolution of technology and the increasing scale at which software is deployed, potentially affecting our societies globally. It is crucial that engineers evaluate more systematically the impacts their solutions can have on individuals, groups, societies and the environment. Ethical risk analysis is one of the approaches that can help

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reduce “ethical debt”, the unpaid cost generated by ethically problematic technical solutions. However, previous research has identified that novices struggle with the identification of risks and their mitigation. Our contribution is a visual tool, the Digital Ethics Canvas, specifically designed to help engineers scan digital solutions for a range of ethical risks with six “lenses”: beneficence, non-maleficence, privacy, fairness, sustainability and empowerment. In this paper, we present the literature background behind the design of this tool. We also report on preliminary evaluations of the canvas with novices (N=26) and experts (N=16) showing that the tool is perceived as practical and useful, with positive utility judgements from participants.

1 INTRODUCTION

The ethical issues with software released to the public, especially Artificial Intelligence (AI)-based software, are so widespread that some researchers have coined the term “ethical debt” (Petrozzino 2021; Fiesler 2020). Paralleling the notion of technical debt (Knesek 2016), ethical debt represents the unpaid cost generated by ethically problematic software and borne by individuals, communities, and society in general. However, while technical debt is typically the result of deliberate choices guided by specific imperatives (e.g. time to market), ethical debt mostly arises from unidentified ethical risks (Fiesler 2020; Petrozzino 2021).

Engineering education has a responsibility to address this situation. Isaac et al. (2022) have shown that novice software engineers tend to neglect ethical concerns in their design. Griffin et al. (2023) report that experienced software engineers do not necessarily identify that technical decisions they routinely make in their professional activities have ethical implications. Whether they will be users, integrators, designers or developers, the engineers we train need to develop strategies for a) systematically identifying and assessing ethical risks associated with digital solutions[2] and b) identifying possible mitigation options to the ethical issues they identify.

In this paper, we present a visual guide called the “Digital Ethics Canvas” designed to help engineering students work through ethical risks specifically related to digital solutions. We first review previous work before discussing the foundations for the ethical framework underlying our canvas and present preliminary evaluation results.

2 BACKGROUND

A “canvas” is a visual tool designed to guide people through the process of using a methodology or framework. Canvases are increasingly used in engineering education (Tranquillo, Kline, and Hixson 2016), for instance to support specific engineering tasks (Ruf and Back 2015) or to support education activities in an engineering context (Ammersdörfer et al. 2022). The canvas that we propose has two specificities: a) it focuses on the analysis of the risks generated by a digital solution under design, development or use and b) it is built on six ethical “lenses” that guide risk assessment and mitigation. In the following, we position our approach compared to existing work on these two aspects.

2.1 Risk analysis

Risk analysis is an important aspect of engineering work and encompasses two types of risks: risks to the product/service being engineered (i.e. hazards that could

[2] Throughout this paper, we use the term “digital solution” to refer to technical systems that involve software and the infrastructure needed to run it. We chose this term to encompass a wide range of software-related technologies, such as IA, Internet of Things, Big Data, social networks or web apps.

make the engineering project fail) and risks generated by that product/service (i.e. adverse effects that the product/service could have on individuals, groups, societies and the environment). While the former are important from a project and business management point of view, the latter are at the core of responsible engineering and the focus of our work. Our goal is to develop the ability of engineers to identify the specific risks generated by digital solutions to others, society and the environment (also called ethical sensitivity).

Vallor (2018) proposes “ethical risk sweeping” as a tool for avoiding “ethical negligence”. She argues that ethical risks analysis should be a standard engineering protocol in the same way as cybersecurity penetration testing, and repeated at all phases in the engineering process, from the initial product proposal to the quality assurance stage. However, her proposal does not make explicit how engineers can analyze these ethical risks in practice.

Carlson et al. (2018) have studied how students analyze risks in the context of projects involving real-world problem solving. They found that students struggled with three aspects of risk analysis: identifying risks, setting priorities and working on mitigation (Carlson et al. 2018). They have proposed two canvases to support students: a Design Canvas to identify risks in the problem space and an Iteration Plan to prioritize and set mitigation goals. However, they define risk as “the probability that the design project fails to make impact”, which does not include risks generated by the impact the design project will make.

Among other methods frequently used in strategic analysis, the SWOT matrix (Strengths, Weaknesses, Opportunities, Threats) includes a risk analysis component within its “Threats” section (Weihrich 1982). However, its main drawback from our perspective is that it also considers only risks to the project. A similar drawback is found in other risk analysis canvases such as (Borbinha, Nadali, and Proença 2015) or (Kuru and Artan 2020).

Taking a different approach, Reijers et al. do not focus on risks per se but on “how a technology might bring about ethical impacts for different stakeholders” (Reijers et al. 2018). Designed for practitioners who do not necessarily have an ethics background, their “Ethics Canvas” implements a four-phase process, from stakeholder and impact analysis to mitigation design. Two clear strengths of the Ethics Canvas are its focus on risks generated by a product/service and its domain-agnostic approach, which makes it suitable for a wide range of disciplines and applications. On the other hand, it might be difficult for novices to think about certain ethical concerns. For instance, while privacy and fairness issues seem to gain increasing visibility in software engineering, other concerns such as sustainability and environmental impacts seem to be less frequently addressed (Isaac et al. 2022). In the next section, we review different approaches that try to tackle this issue.

2.2 Ethical lenses

Value-oriented methodologies such as Value-Sensitive Design (Friedman, Kahn, and Borning 2002) typically approach the range of ethical concerns by having stakeholders identify explicitly the “human values” that the product/service should align with. Value-based approaches are getting a lot of traction in engineering and are sometimes even referred to as “ethics by design” approaches (Spiekermann and Winkler 2020). Focusing on values can be seen both as a strength and a weakness: on one hand, the contextual nature of values makes these approach flexible and adaptable to a broad range of contexts, but on the other hand, appropriately defining the values at stake and frame them so that they mean the same thing to all parties

can be challenging (Friedman et al. 2021). The very concept of value has actually been deemed unclear and insufficiently defined (Manders-Huits 2011).
Some authors argue for a more normative approach based on predefined ethical principles (Manders-Huits 2011). Cardia et al. (2017) for instance, propose a canvas based on the four humanitarian principles (humanity, neutrality, impartiality and independence) to assess the use of digital technology for humanitarian action. The four bioethics principles (beneficence, non-maleficence, autonomy, and justice) are often used as an ethical framework for evaluating engineering solutions in healthcare contexts, such as in (Cawthorne and Robbins-van Wynsberghe 2020). By definition, principle-based approaches are possible only when there is an overall agreement on the set of ethical principles to use. This is the case for the humanitarian domain (Council of the EU, European Parliament, and European Commission 2008) and for the medical domain with the largely adopted principles of biomedical ethics (Beauchamp and Childress 1979). As we will discuss in the next section, this is not (yet) the case for the digital domain. In addition, the engineers we train will work in a variety of contexts with varying sets of values (e.g. healthcare, social media). This is why we adopt instead the notion of ethical “lenses” as proposed by Isaac et al. (2022), which represent multiple ethical perspectives for analyzing risks.
The five “lenses” from Isaac et al. (2022) stem from the human-centered design criteria feasibility, desirability and viability (IDEO 2000) that the authors extended with sustainability, privacy and accessibility. Guiding analysis with several criteria is also found in the PEST/PESTLE framework (Political, Economic, Social, Technological / Legal, Environmental). Meant for “scanning” macro-environmental factors in business development (Aguilar 1967), this framework is often used in combination with SWOT. Other authors have instead reinterpreted existing canvases in light of such criteria. For instance, Gillet et al. (2022) propose two reinterpretations of the Value Proposition Canvas (Osterwalder et al. 2014), focused on sustainability and transparency. In contrast to this approach and with the goal to help engineers “scan” risks from multiple ethical perspectives, we propose a single canvas that implements several ethical lenses. In the following section, we discuss the ethical lenses we chose in light of the existing literature on ethics in the digital domain.

2.3 Digital-specific ethical lenses

With the increasing visibility of ethical issues with digital solutions, researchers and practitioners have attempted to clarify adequate ethical guidelines. A significant number of proposals stem from the Big Data and Artificial Intelligence domains. In their “Data, responsibly” proposal, Stoyanovich, Abiteboul, and Miklau (2017) recommend fairness, diversity, transparency, equality and data-protection as the foundations for responsible data science. Ballantyne (2018) later argues that “there is no one-size-fits-all framework for how to ethically manage your data” and suggests seven ethical values for “making informed, explicit, and justifiable trade-offs, rather than following a set of prescribed rules”: social value, harm minimization, control, justice, trustworthiness, transparency and accountability. Howe and Elenberg (2020), take a medical research stance and suggest autonomy, equity and privacy as the ethical concepts most challenged by big data in health. Interestingly, the issue of sustainability and environmental impact is mostly absent from these proposals.
In the domain of AI, Jobin, Ienca and Vayena (2019) analyzed 84 documents in the context of the “ethical AI debate” to identify whether a global consensus was emerging. They identified that 88% of the documents had been published after 2016 and conclude that “No single ethical principle appeared to be common to the entire

corpus of documents, although there is an emerging convergence around the following principles: transparency, justice and fairness, non-maleficence, responsibility, and privacy.”. Loi, Heitz and Christen (2020) extended this work with a focus on the procedures recommended in these AI ethics guidelines and propose a framework with seven principles: beneficence, non-maleficence, autonomy, justice, control, transparency, accountability. Ryan and Stahl (2020) also extended the work from Jobin et al. but with the goal of providing the most comprehensive list of ethical principles as found in 91 guidelines. It is the only contribution we found that included sustainability and environmental impact, reflecting an overall lack of attention to a pressing issue to which digital solutions are actually no stranger (Bender et al. 2021). Other authors take a radically different approach and put forward the human rights framework as a cross-cultural and globally agreed framework for responsible AI (Prabhakaran et al. 2022).

With this short review we want to highlight the current lack of consensus on the ethical principles that should guide a responsible approach to software. It is important to note that this landscape is moving extremely fast and is influenced, of course, by the crucial work done on software and AI regulation worldwide. A flagship of this work is probably the “Artificial Intelligence Act” from the European Commission, which follows a risk-based approach to classify AI-based systems in terms of impacts on safety, security and fundamental rights.

In terms of canvas-based approaches, we found one digital-specific ethics canvas: the Technology Impact Cycle Tool (TICT) (Fontys University 2021). Focused on reflection, it uses questions organized in “scans” of progressive scope with 10 different categories: impact on society, human values, privacy, inclusivity, transparency, bad actors, sustainability, data, stakeholders and futuring. While we found the organization in progressive scopes helpful, we thought that the tool had too many categories and was mixing design process aspects (e.g. stakeholder analysis) with ethical lenses (e.g. privacy, sustainability). We also argue that, while reflection is certainly important in responsible design, an analytical approach of the risks generated by a solution is essential to reducing ethical debt.

3 THE DIGITAL ETHICS CANVAS

As our review highlighted, very few options exist to help engineers identify and mitigate the range of ethical risks generated by a digital solution under design, development or use. Our contribution is a canvas (Figure 1), that helps engineers to scan the risks generated by a solution with six digital-specific ethical lenses: beneficence, non-maleficence, privacy, fairness, sustainability and empowerment. Following an incremental process and taking inspiration from the bioethics principles in particular, we have integrated ethical lenses progressively into our canvas. Our “beneficence” lens is positively oriented, for documenting the expected benefits of the solution. The “non-maleficence” lens is meant to capture safety and security issues, as suggested by Ryan and Stahl (2020). Our “empowerment” lens reflects the autonomy principle but with a larger scope to encompass issues of transparency, explainability, trust and user agency. Our review showed that “justice” and “fairness” are often grouped together (see previous section) but we chose to use “fairness” as a less normative concept which is more frequently used in relation to AI-based solutions. Finally, we added a “privacy” lens to capture risks with regards to the use of data and “sustainability” to include risks related to environmental impacts and labor exploitation. An important factor in our choice was to limit the number of lenses not to overwhelm novices, while being general enough to capture a range of ethical risks. We were also careful not to be too Big Data- or AI-specific and made sure our canvas can be applied to other types of digital solutions. For scaffolding purposes, we included questions in the canvas for the different lenses to help our users surface elements in the digital solution that are likely to give rise to risks, rather than providing them with definitions (see Figure 1).

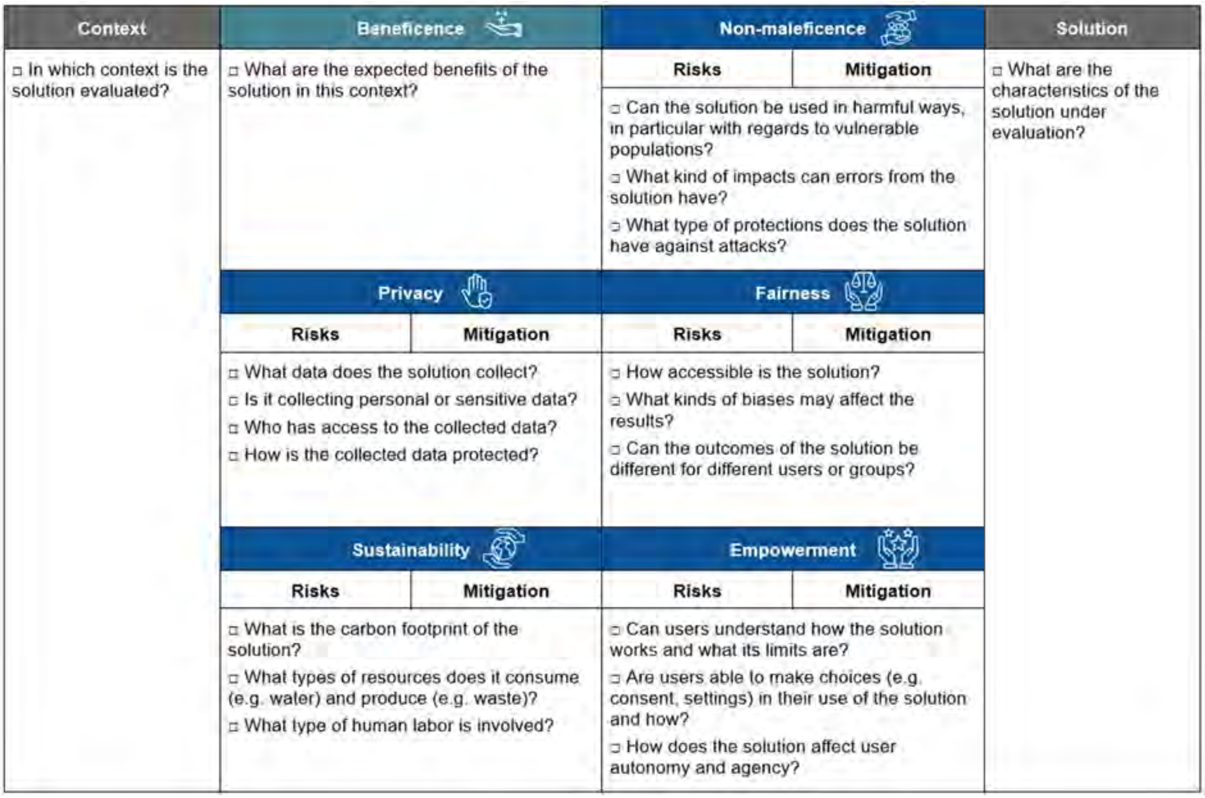

Figure 1: The Digital Ethics Canvas. The left and right columns are used to map out factual information about the digital solution and the context, whereas the central part is used for evaluating the benefits, risks and mitigation options for the solution using our ethical lenses.

With one benefit-oriented lens and five risk-oriented lenses, our canvas supports users in benefit-risk analysis, a methodology which is widely used in public (European Medicines Agency 2018). Benefit-risk analysis is part of a broader family of Multi-Criteria Decision-Making methods (Zionts 1979), typically used in the case of multiple conflicting objectives, as is generally the case with ethical decisions. This type of analysis requires collecting information about the problem space and context, which is why our canvas includes sections to map out factual information about the digital solution and its context of use. For each of the risks, mitigation strategies can be described, as these can weigh in the analysis. Depending on whether the canvas is used at design/development or at use time, mitigation strategies may involve either modifying the technological artifact (e.g., avoid collecting personal data that is not needed to reduce a privacy risk) or changing the usage context (e.g., ask users to provide a nickname rather than their actual name).

4 EVALUATION

4.1 Methods

We have developed our canvas incrementally, testing our ethical lenses and our approach with different types of audiences and applications. In this paper, we report the results of two small-scale evaluations conducted in the spring semester 2023.

We collected the views of novices in a three-hour session dedicated to responsible design as part of a master course on Information Systems Design with 26 students of various backgrounds (15 women, 11 men). We facilitated an interactive presentation of the canvas and its ethical lenses, then students applied the canvas on a case study, followed by a class discussion. The second evaluation was a part of a 90-minute workshop on the ethics of using generative AI for education, for experts in the fields of ethics, engineering, and education. The experts had various backgrounds and levels of seniority (N=16, 11 women, 5 men). We introduced our ethical lenses one after the other with inputs from research on generative AI and time for analyzing the corresponding risks in a given scenario (e.g., a teacher using generative AI to generate deepfakes instead of recorded lectures).
At the end of each session, we asked participants to fill out a survey with both affective reactions and utility judgment measures (Alliger et al. 1997). We captured participants' perceptions about the canvas with the AttrakDiff questionnaire (Hassenzahl, Burmester, and Koller 2003), which has 10 items with pairs of opposite adjectives and a scale from 1 to 7, every other item being reverse-scored. In addition, participants were asked “How would you describe the canvas to your friends?”. The second part of the survey asked participants their perceptions about several aspects of the session on a 4-point likert scale. To assess the perceived utility of the canvas, we asked participants if they thought what they had learned in the session would be useful to them later, if they were likely to apply what they learned in other contexts and if they wanted to have access to the canvas for further use. For novices, learning outcomes were also evaluated in a mid-term exam question the following week.

4.2 Results: perceptions about the canvas

The results of the AttrakDiff items are shown in Table 1. All the adjective pairs are presented with the negative adjective on the left (valued 1) and the positive on the right (valued 7), taking reverse-scoring into account. For each question, we indicate the mean score and standard deviation for both the novices and the experts. The star notation indicates when the mean score is significantly different from neutral (4) as assessed with a single-sample t-test.
The most statistically significant measures indicate that both novices and experts found the canvas ‘good’ (M = 5.92 for novices and M = 6.44 for experts respectively), ‘practical’ (M = 5.35 and M = 6.06) and ‘useful’ (M = 5.84 and M = 6.50). One more measure is statistically significant for the experts suggesting they also found the canvas ‘stylish’ (M = 5.81). All other mean scores are above the neutral value (4 of 7) and a majority higher than 5. These results indicate that the canvas was perceived positively and found to possess pragmatic qualities by both the novices and the experts, a valuable attribute for an education tool for engineers. Overall, the experts report a more positive perception of the canvas than novices. While this is probably to be expected, it also indicates for us an opportunity to further tailor the canvas for novice users, for instance by developing the educational resources around our canvas (e.g. an accompanying quick start guide). The only scale where experts rated the canvas lower than novices is the “complicated - simple” scale. We relate this to the fact that experts had much less time to practice with the canvas than novices.
Most of the novices provided a description of the canvas, with mostly positive responses such as: “A simple model to assess complex 'blurry' topics”, “Tool to help you remember/realize the different aspects of a project that you don't necessarily think of intuitively.” and “As a good way to break down and analyze the important

aspects of different phenomena". A few responses were mixed, such as: "A good tool but could be simpler." and "Complicated but interesting". Only a few experts provided a textual description of the canvas, such as "A useful thinking tool.", "Matrix for structured evaluation" or "As a useful tool to consider in teaching witch's of AI". It is interesting to note how a number of novices contrast the practicality of the canvas with the complexity and non-intuitive aspects of technology ethics, which we take as a positive indicator of the value of the canvas for educational purposes. The more mixed descriptions by novices further encourage us to refine the instructional design of our canvas and our introduction session.

*Table 1: Results of the AttrakDiff questionnaire, with differences from the neutral response (4) tested with single-sample t-tests (*** for p < .001, ** for p < .01 and * for p <.05).*

	Negative pole (1)	**Positive pole (7)**		**Novices (N=26)**	**Experts (N=16)**
Attractiveness (ATT)	Bad	Good	Mean (SD)	**5.92***** (1.12)	**6.44***** (0.81)
	Ugly	Attractive	Mean (SD)	4.5 (1.57)	5.56 (1.21)
Hedonic Quality - Identity (HQ-I)	Unimaginative	Imaginative	Mean (SD)	5.35 (1.26)	6.00 (0.89)
	Dull	Captivating	Mean (SD)	5.23 (1.61)	6.25 (0.58)
Hedonic Quality - Stimulation (HQ-S)	Tacky	Stylish	Mean (SD)	5.12 (1.48)	**5.81**** (1.05)
	Cheap	Premium	Mean (SD)	4.92 (1.38)	5.81 (1.11)
Pragmatic Quality (PG)	Confusing	Clearly structured	Mean (SD)	5.73 (1.22)	5.94 (1.29)
	Complicated	Simple	Mean (SD)	5 (1.10)	4.31 (1.54)
	Impractical	Practical	Mean (SD)	**5.35*** (1.44)	**6.06***** (0.85)
	Useless	Useful	Mean (SD)	**5.84***** (1.25)	**6.50***** (0.52)

4.3 Results: quality of the session and utility judgements

The perceptions of novices and experts about the facilitation of the sessions are illustrated in questions 1 to 4 of Figure 2. The majority of participants agreed or strongly agreed with all the positive statements. Notably, 95.9% of novices and 100% of experts found the session good. Experts were a bit less positive than novices on the time allowed for questions, which we relate to the relative short duration of the workshop compared to the course.

Utility judgements of the participants are represented in questions 5 to 7 of Figure 2. Participant's evaluation of the usefulness of the session is positive with 75% of novices and 87.6% of experts agreeing or strongly agreeing. A high proportion of participants (66.6% of novices and 81.3% of experts) also reported they were likely to apply what they had learned into other contexts, which is a positive indicator of both learning and transfer (Alliger et al. 1997). Finally, the majority of respondents (62.5% of novices and 75% of experts) indicated they would like to have access to the canvas for other tasks. While this evaluation is promising, we observe that novices are overall less positive in their utility judgment than experts. This is to be contrasted with the results in terms of learning outcomes, where novices scored an average grade of 74%. Their less positive utility judgments might be due to the fact that, at the time of the session, they had not yet started to work on their course project and might not have directly seen how to apply the canvas in a concrete context. If that explanation proves to be correct, it would underline the importance of combining such an ethical canvas session with a concrete real-life project.

Novices (N = 26) **Experts (N = 16)**

Figure 2: Results of the questionnaire (4-item Likert scale) on the perceptions about the session (questions 1 to 4) and utility judgements on the canvas (questions 5 to 7).

5 SUMMARY AND ACKNOWLEDGEMENTS

In this paper, we address the issue of ethical debt by proposing a canvas for engineers to analyze more systematically the ethical risks with a digital solution at design, development or use time. Our canvas includes six ethical lenses (beneficence, non-maleficence, privacy, fairness, sustainability and empowerment) that are specific to the digital domain and implement a benefit-risk analysis framework. We presented an overview of the literature behind our approach as well as a preliminary evaluation of our canvas by engineering ethics novices and experts. The results proved positive, our canvas being perceived as practical and useful by participants, which is promising for use in engineering education. We plan to further refine our instructional resources around the canvas to provide users with more scaffolding, and to further evaluate how this canvas can be used in various settings.

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SETTING UP AN ENGINEERING "PILOT STUDY PROGRAM" IN E-MOBILITY FOR INTERNATIONAL STUDENTS: ISSUES AND SOLUTIONS

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Conference Key Areas: *Addressing the challenges of Climate Change and Sustainability, Recruitment and Retention of Engineering Students*
Keywords: *electromobility, development of a new international study program, issues of non-EU students*

ABSTRACT

This practice paper presents the issues and solutions in introducing a new international engineering study program at a German university that attracts especially non-European students. The master's program electromobility with the four majors Artificial Intelligence and Autonomous Driving, Connectivity, E-Powertrain and Sustainable Mobility & Production Technology was newly introduced in the winter semester 2022/23. It combines the expertise of all engineering departments like mechanical engineering, electrical engineering, computer science and artificial intelligence, materials science and chemical engineering to offer a

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modern and attractive engineering education for sustainability in an ecologic and economic important field. The high amount of applications with more than 1600 applicants per semester shows the high visibility and attraction of this study program. As the international master’s program is offered in English language, especially students e.g. from India, Pakistan or Bangladesh who already have a bachelor’s degree taught in English language are interested in this program. The selection of future students out of a high number of applications is challenging, while this process has to be completed in a very short period of time. With this high number of international students, further issues occur regarding visa application, housing and other organizational aspects. Practical solutions are presented in this paper that lead to transferable recommendations for the future design of such large-scale study programs for other universities.

1 INTRODUCTION

1.1 Current trends for the future of mobility

One of the greatest challenges in this century is the global climate change that affects people and their environment all around the world to varying degrees and demands new research projects from various disciplines. E-mobility is a key technology for climate-friendly mobility. The discussion about banning internal combustion engines in the European Union by 2035 shows how important these alternative drives will be for the future of mobility. Along with research, education must also be adapted to changing issues. The study program e-mobility matches these current trends and was developed as an international "pilot study program" starting in winter semester 2022/23. The international orientation may lead to enhanced cooperation between different nations. Furthermore, international students are welcome to stay and work in Germany after they will have finished their studies. This may counteract the shortage of skilled workers that employers are facing in the German industry.

1.2 Setting up a new international pilot study program in e-mobility

A survey of common literature on this topic lead to a study of the global management consulting firm McKinsey & Company [1] that identified four trends in the field of mobility. These are Autonomous driving, Connected cars, Electrified vehicles and Shared mobility. Although e-mobility is a megatrend, dedicated study programs "e-mobility" (not just "automotive engineering" with a major in electrical driving) are relatively rare at German universities. The homepage "studienwahl.de" is the official information portal of the Federal Republic of Germany for study programs. It lists only about 10 universities in Germany with a dedicated e-mobility master's program and most of them are in German language [2]. Considering the curricula and competence profiles of these study programs and especially based on the McKinsey study [1], the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) decided to develop its new study program e-mobility with the four majors Artificial Intelligence (AI) & Autonomous Driving, Connectivity, E-Powertrain and Sustainable Mobility & Production Technology [3]. Referring to the existing curricula in e-mobility in Germany, the study program also comprises competencies in the field of mechanical and automotive engineering, electrical engineering, computer science, artificial intelligence and materials science in fundamental courses. As e-mobility is an interdisciplinary field, all departments from the faculty of engineering are involved.

2 METHODOLOGY

The methodology presented in this paper consists of the following steps:

1. Conception and implementation of the new pilot study program e-mobility
2. Identifying common issues of the first two student cohorts
   (winter semester 2022/23 and summer semester 2023)
3. Structuring of the common issues in research questions (RQ)
4. Answering the research questions with transferable solutions

The following research questions according to step 3 were derived from the issues to structure the elaborated knowledge. This leads to solutions that are transferable to similar problems at other universities within and beyond the SEFI community:

- RQ1: How can the popularity for newly established international study programs be increased worldwide?
- RQ2: What evaluation options are suitable for admission in the case of large application numbers?
- RQ3: Which issues occur especially for non-EU-students and how can you solve them?

3 RESULTS: ISSUES AND SOLUTIONS

3.1 Gaining visibility and attractiveness (RQ1)

While the bachelor program is offered in German language, the international master’s program was designed bilingual, so students can choose to study in German or in English language. Due to the offered program in English, international students were expected to be attracted, here especially applicants who already studied in English during their bachelor’s degree. These students are typically from countries like India, Pakistan or Bangladesh and usually have a very good knowledge of English. When opening the application phase for the new study program in spring/summer 2022, the FAU did not expect more than 300 applications for the international master’s program in the first semester. From experiences with new study programs in German language it was known that it takes up to 1-2 years, until these new study programs are renowned in the target group. Beside information about the new study program at the university study homepages, the following measures were conducted to increase popularity:

- "Premium entry in International programs in Germany" was offered at DAAD (German Academic Exchange Service) [4].
- The structure of the study program with some majors in mechanical engineering, electrical engineering or in AI opened up a wide field of applications from bachelor graduates, mostly in mechanical, electrical, vehicle or automotive engineering.
- A study start is offered not only once a year, but in every semester (see also Table 1).

Fig. 1 shows the development of numbers of applications for the international master’s program. The mentioned measures were suitable to gain visibility and attractiveness. Especially, the DAAD premium entry was very successful to attract students. All these measures resulted in a high number of applications in the first year that raised even more in the following semesters. In the upcoming winter semester 2023/24 there are even more applications expected. Currently, an average of 20% of the applicants get an admission to the master’s program. In the past semesters, most of the admitted applicants decided to start their studies resulting in high numbers of freshmen of about 200-450.

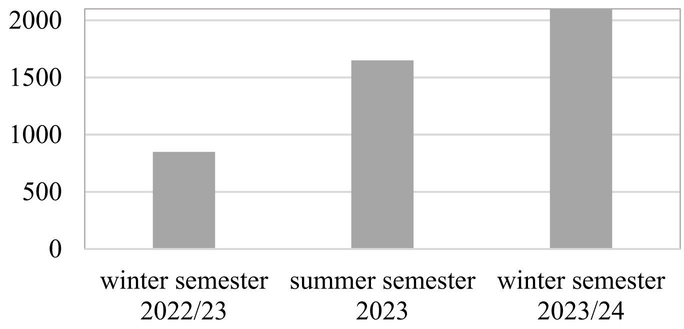

Fig. 1. Development of numbers of applications from winter semester 2022/23 to winter semester 2023/24

3.2 Suitable evaluation options for admission in case of large application numbers (RQ2)

When the new study program was introduced, there was a high level of uncertainty about the number of prospective applicants. Furthermore, it was not clear, how many of the admitted applicants would enroll in the program. The transition from paper applications to online applications was performed at the university during the Covid pandemic, resulting in a university-wide doubling of applications for international study programs.

Due to the high number of applications, individual interviews could not be conducted. Furthermore, tests in presence could not be offered due to the high percentage of non-EU-applicants. Therefore, the evaluation process is performed mainly based on the submitted documents. Since the applicants not only come from different countries and universities but also apply with different bachelor's degrees e.g. in mechanical or electrical engineering, a suitable evaluation approach has to be set up to compare the qualifications and achievements of the applicants. Therefore, the evaluation committee had to deal with the following aspects:

- Comparison of achieved modules that are relevant for the master's program with the bachelor program e-mobility of FAU
- Conversion of grades from other countries to the German university grading system
- Language certificates and proficiency tests to assure good knowledge in English (Level C1 in the Common European Framework of Reference (CEFR))
- Admission tests (open book or proctored)
- International comparisons and rankings to evaluate degrees from different universities and countries
- Further qualifications e.g. work experiences, motivation
- Examination of admission with conditional modules that must be completed as part of the master's program

The evaluation procedure comprises a formal check by the master’s office of FAU and a professional review by the evaluation committee of the study program at the department. The application and evaluation procedure is shown in Fig. 2, starting with the preparation and submission of the application by the applicant.

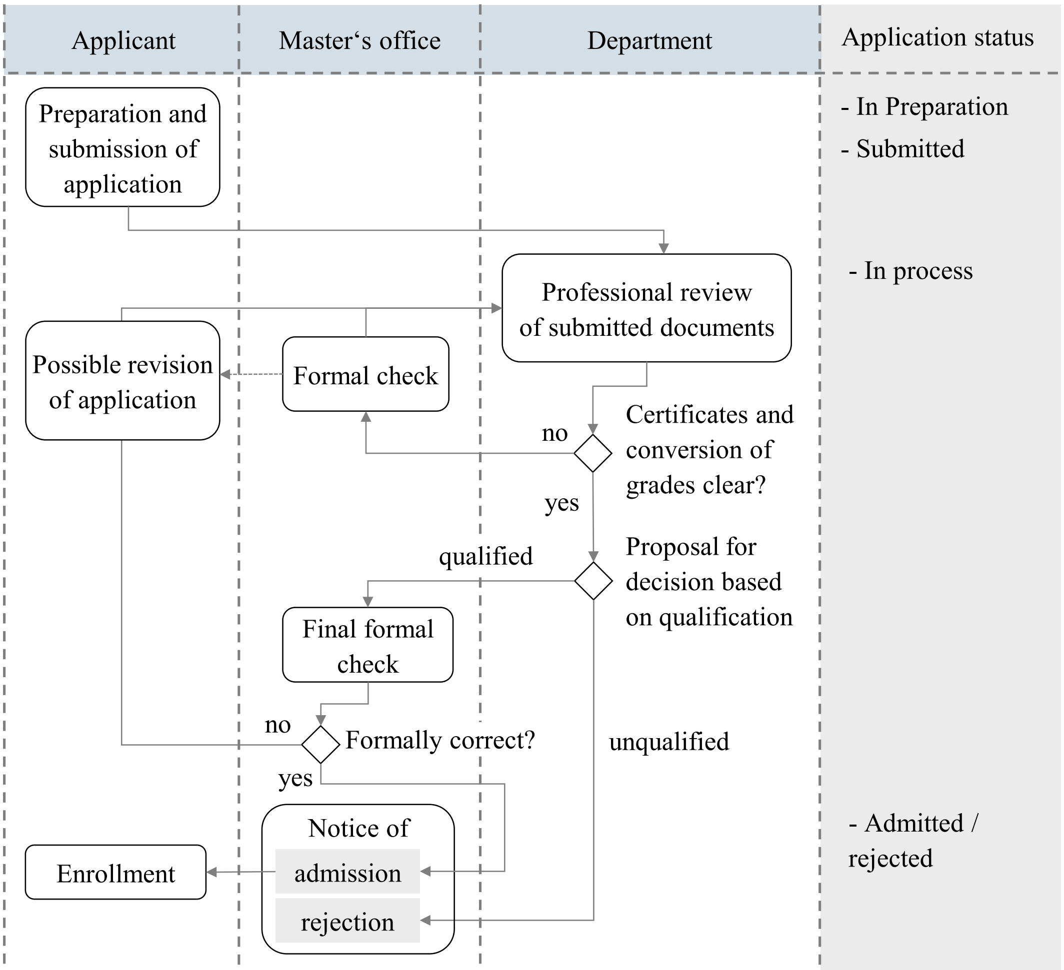

Fig. 2: Application and evaluation process for the international master’s program

The application numbers are very high, most of the applicants (>85%) submit their application formally correctly and an average of only about 20% of the applicants currently are accepted in the professional review due to the high requirements for study entry. Therefore, the professional review is performed in the first evaluation step **before** the formal review by the university-wide master's office. Only in case of unclear formal issues, e.g. unclear submitted certificates or false conversion of grades, a request for formal check is sent to the master’s office as first step of the evaluation. In that case, the formal check is done already at this point in the evaluation process to enable appropriate professional evaluation by the committee at the department. After the professional review, the evaluation committee makes a proposal for decision. If the evaluation shows that the applicant is not qualified, there will be a rejection and no further formal checking is necessary. If the committee decides that the applicant is qualified for the master’s degree, there is a final formal check before the applicant will receive the notice of admission and will then be able to enroll in the study program.

The advantage of this procedure is that the master’s office does not need to check every application formally. The formal check is only done after a request or for those applicants who are qualified based on the evaluation at the department. Especially in the case of high number of applications, this is an appropriate way to relieve the master’s office.

3.3 Issues and solutions that occur especially for non-EU-students (RQ3)

Major problems occurred especially for non-EU-students regarding the application for visa and entry to Germany. It has to be considered that applicants often have to wait for several months to get an appointment at their embassies. In the first semesters, many admissions were issued at too short notice. Therefore, the application period will start and end earlier from this semester on so that the committee is able to evaluate the applications earlier. Non-EU-students will need at least four months for preparation, visa acquisition and finding housing. Another way to speed up visa processes is that the master's office informs the DAAD about admitted applicants regularly. Students from countries like India or China need a certificate from the Academic Evaluation Center (in German: "Akademische Prüfstelle (APS)"). The APS certificate is a mandatory part of the documents that have to be submitted for visa applications. Therefore, already admitted applicants will be prioritized for their APS certificate in the German embassies.

Many students were not able to arrive in time in the first semesters. Therefore, as a pilot program, the study program offers many lectures online so that the students were able to start studying while still waiting for their visa. It took great efforts to assemble enough online classes in all of the four majors. As exams are usually taken in presence, these students need to arrive in Germany until the exam period starts at the end of their first semester. If they will not be able to arrive, they may de-register and apply again for the upcoming semester. Anyway, they will be able to take the exams in the next semester, as exams are usually offered twice a year in both winter and summer semester.

Finding accommodation in cities with more than 100 000 inhabitants is challenging, especially if it has to be completed in a short period of time. It might be easier for students to find accommodation in summer semester, as in general most of the students, especially bachelor students, start studying in winter semester.

There are some advantages and disadvantages of a study start in summer semester as shown in Table 1. The advantages regarding the flexibility and attractiveness of the study program (see also section 2.1) and finding housing were already mentioned. Especially these two aspects contributed to the decision to offer an additional study start in summer semester. In addition, the administration tasks will be spread over the whole year. The main disadvantage of a study start in summer semester in general is that it is often not possible for bachelor’s programs with their relatively fixed structure, e.g. Math 1 followed by Math 2 followed by Math 3. As master’s programs often have more flexible structures, it is easier to offer a summer start there.

Table 1. Pro’s and Con’s for additional study start in summer semester

Advantages	Disadvantages
• More students are attracted as they do not have to wait until the next winter semester if they want to study in a master’s program • Finding student housing might get easier as the students do not compete with bachelor’s freshmen who start to study in winter semester • The tasks for administration of the applications are spread over the whole year	• Difficult to realize in bachelor’s programs, where many modules build on each other, while the realization is much easier in master’s programs with more flexible study structures • Applications and study information events must be handled each semester

Especially international students have a lot of questions regarding their studies in a foreign country that may differ in organization of their previous studies. Therefore, it is necessary to give detailed advice on the procedures, their studies and general issues.

4 SUMMARY

Based on the practical experience with the new international pilot study program, issues and solutions were discussed in this paper. The following conclusions are drawn that should be taken into account when planning and setting up a new international study program:

- Global trends and interdisciplinary research areas affect the popularity of international study programs. Different majors in a master’s program open up the possibility for applications from different bachelor’s programs.
- The evaluation procedure has to be suitable for the respective number of applicants. With a high number of applications, the professional review is performed first; a full formal check is performed later only if necessary.
- An early start and end date of the application period is necessary to issue admissions early enough, so that foreign students will have a chance to prepare for their studies at the university. Non-EU students need at least four months for visa application for Germany.
- A study start twice a year (each semester) is recommended if the structure of the study program allows it.

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THE POWER OF PERSPECTIVE DIALOGUE: UNLOCKING TRANSFORMATIVE REFLECTION IN ENGINEERING EDUCATION

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ABSTRACT

Engineers need to be socially responsible, ethically aware and deliver positive contributions to the wicked problems[2] of today's global challenges. In navigating these challenges, being able to reflect is a necessary prerequisite. But if we simply ask students reflective questions, they tend to give us mostly socially desirable answers. Our university initiated an institute-wide program focused on creating learning experiences and environments for transformative reflection instead of superficial reflection. In this paper we present design principles for transformative reflection based on a literature overview and the program's accumulated experience. The principles are I) Six domains for reflection on engineering issues, II) The differentiation between the internal and external perspectives, III) Our approach to

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[2] The term 'wicked problem' refers to that class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing (Churchman, 1967).

design for context-specificity of transformative reflective experiences, and IV) Four mechanisms that foster transformative reflection.

1 INTRODUCTION

Our complex, fast-changing world is intertwined with technology (Australian Council of Engineering Deans 2021) and our planet and humankind are facing many challenges, including climate change, pollution, social injustice, energy transition, affordable healthcare, etc. (Gürdür Broo, Kaynak, and Sait, 2022). Engineers are part of the multidisciplinary teams that will address such challenges. However, successful team members require a skillset that has not been strongly considered in engineering education (Hirsch and McKenna 2008; Gürdür Broo, Kaynak, and Sait 2022; Schuelke-Leech 2020). Transversal skills deemed important for teamwork such as communication found their way into engineering curricula, yet skills such as reflection, resilience, or the ability to reassess choices if a situation changes, awareness of ethics, social injustice, bias, and unintended implications of engineering practice have not.

Schön introduced the concept of reflection in the broader academic discourse with his seminal book on reflective practitioners in 1983 and the concept has been "widely and diversely used" (Kember et al. 2008, p 369). Reflection is directly related to self-awareness, to improving learning outcomes, to developing professionally and to understanding others (Chan & Lee, 2021). Mello and Wattret (2021) postulate that reflection is a conditional skill that enables students to develop other transversal skills, such as resilience and communication skills. The call to embed reflection in engineering curricula has been explicitly stated by authors such as Turns et al. (2014), and Chan and Lee (2021), or implicitly assumed by other sources such as the MIT mission statement that includes reflection as an implicit prerequisite for solving the global challenges (MIT, 2022) and the TU Delft criteria for Bachelor programs (Meijers et al, 2005). In this paper we present the first steps in creating an institution-wide program to develop integrations for reflection in the curriculum. We present a literature overview on barriers to implementing reflection, which we complement with our own experiences and reflections, and we present instructional design principles for transformative reflection.

2 REFLECTION IN ENGINEERING EDUCATION: EASIER SAID THAN DONE

There are many reasons why embedding reflection in engineering curricula is challenging. In this section we present a literature overview (Grant and Booth, 2009) on why it is challenging and what barriers get in the way. We complement the literature overview with outcomes of participatory research with engineering educators in our institution in 2021 and 2022 (Hermsen et al, 2022).

Reflection can mean many different things in many different contexts, and different fields of application have different definitions (Chan, Wong, and Luo 2021; Akbari 2007; Cotton 2001; Tsingos, Bosnic-Anticevich, and Smith 2014; LaBoskey 1994). Reflection involves carefully evaluating and making sense of one's behavior, beliefs, and perspectives , which can lead to both useful insights and uncomfortable realizations of weaknesses or mistakes (Chan, Wong, and Luo 2021; Mezirow 1998; Boud, Keogh, and Walker 1985; Grant, Franklin, and Langford 2002). Facing personal aspects can be experienced as difficult and even threatening, causing self-doubt and non-constructive self judgments (Hobbs 2007; Bharuthram 2018). Lönngren (2017) stated that reflection is often considered to be in tension with the technology-oriented culture of engineering sciences, which prioritizes measurable outcomes and linear problem-solving (see also Schuelke-Leech, 2020). This conflict is caused because reflection involves abstract connections and perspective-taking, and is often associated with dealing with emotions and vulnerability. As a result, many engineers perceive time spent on reflection as time lost on disciplinary knowledge (Hobbs 2007; Chan, Wong, and Luo 2021; Bharuthram 2018). This prospect may make instructors reluctant to reflect or incorporate reflection into their teaching and have students engage with it.

Meaningful reflection does not happen by itself: Meijers and Mittendorf (2017) found that, in spite of teachers' attention to reflection in assignments, students often provide socially desirable responses and struggle to find meaning in reflective exercises if they receive little instruction or guidance. In technical subjects it is important to scaffold, and the same goes for learning to reflect, as reflection without instruction and practice results in superficial reflections that have a minor impact on learning at best (McIntosh 2010; Ryan 2013). Instructors and students find it challenging to integrate reflection in daily practice and provide meaningful guidance through the process (McIntosh 2010; Ryan 2013). Students experience reflection-fatigue when they are asked to reflect on a regular basis (Kinkhorst 2010) or even turn into ‘reflective zombies’, which happens when reflection becomes superficial, repetitive, unproductive or even counterproductive (De la Croix and Veen 2018; Bharuthram 2018).

Although there is a considerable body of knowledge on the topic of reflection, authors often fail to describe how their design and application of reflection have been tailored to a specific context. This makes it hard for instructors to understand how to take contextual factors into account in their own courses. Some publications on reflection are highly theoretical and strongly rooted in philosophy, while other publications are very practical, yet often do not apply to the instructor’s context. Assignments for meaningful reflection need to hit a sweet spot, as assignments need to have a certain level of practicality for students to be able to relate to it, yet by making it too practical it can easily end up becoming a tick-box activity, where the recording of compliance with assessment requirements is more prevalent than actual learning (Barak 2006; Platt 2014).

There are practical barriers to implementation of reflection in coursework. Searches for articles on reflection in (engineering) education tend to yield many hits that include publications on education as well as the subject of reflection, which makes it overwhelming for laypersons to find appropriate resources. From an instructional design perspective, there are many supporting or limiting factors for (classroom) assignments: how big is the group, what year are students in, how familiar are these students with reflection, what kind of learning activity is it part of? Is the physical space safe and inviting, are there any language barriers present, when should reflection be scheduled, and will there be opportunities to provide feedback and debriefing to the reflection exercises? Due to all these challenges instructors may lack confidence or feel resentful about delivering guidance for reflection, as it adds to their workload or ‘distracts’ them from research practice (Beard, Clegg, and Smith 2007; Platt 2014), while the benefits are not always clear. Creating meaningful opportunities for students to reflect is hard, and real, visible impact for students is far from guaranteed. Without tackling these challenges reflection will remain an afterthought in engineering education, rather than an integrated activity.

3 THREE MAIN ELEMENTS OF STRUCTURAL ATTENTION FOR REFLECTION

Schaepkens and Lijster (2022) argue that meaningful reflection needs to bridge two gaps: 1) the gap between theory and practice and 2) the gap between an individual and their community (p.3). Schaepker and Lijster follow Kant in arguing that reflection resists systemization and can not be taught: it can only be practiced as reflection needs a context and there are no definite rules that can address all contexts. Additionally, individuals and communities always change, so the gap between individual and communal sense requires a continuous dialogue, not a set of rules. However, without structural attention for practicing reflection students will not develop skills to reflect on their praxis in a meaningful way. Our university initiated an institution-wide program that recognizes the importance of reflection and aims to embed meaningful reflection in our engineering curricula. In this section we describe four main elements of our program.

Element 1: There are many ways to do reflection
Within the program we do not advocate 'one right way' for reflection. Instead, we aim to create a vision of the possible role and use of reflection in engineering education that leaves enough room for instructors to adapt to specific contexts. The program aims to be supportive, not prescriptive, to instructors who wish to integrate reflection in their courses. We see reflection as a process in which engineers stop and take time to use their thoughts and feelings to make sense of an experience or issues, and to yield insight into themselves and into how they relate to the world around them so that they can grow and/or change their actions. There is no shortage of literature about how to “do” reflection, originating from a variety of research fields, such as education, psychology, healthcare, management and philosophy (Mina, Cowan, and Heywood 2015; Fleck and Fitzpatrick 2010; Gordijn et al. 2018; Keestra 2017; Marshall 2019). We do not oppose any models these authors propose and our practice of reflection is not a substitute. Yet, instead of prescribing one way to ‘do’ reflection, we provide information, structure, vocabulary, and awareness to instructors to make an informed choice in the use and purpose of reflection.

Element 2: Six domains of reflection
We frame reflection in the context of engineering education and distinguishing six domains to reflect on. That way reflection becomes a concept that instructors and students can grasp more easily. The six domains were identified through an institution-wide exploration of what reflection is (Hermsen et al., 2022). These six domains are:
1 - Society: reflection on social themes and challenges. For example, climate change, inclusion and equity, affordable healthcare, sustainable infrastructure and mobility, energy transition, circular economy, and others.
2 - Product: reflection on the various stages of developed models, prototypes, policies, procedures, services and /or research. For example, on weighing requirements, balancing impact, the value, and limitations, etc.

3 - Process: reflection on the (sub)conscious choices made in the process and the way they influence outcome. For example: going over activities, looking at blind spots and assumptions, examining successes and mistakes.
4 - Interaction and collaboration: reflection on interactions and collaboration with peers or supervisors. Reflection on for example to understand others, prevent, manage, and solve conflicts.
5 - Learning: reflection on learning strategies, assessments, ambitions, attitudes, targets, motivation, personal development, and ownership of learning.
6 - Oneself: reflection on one's behavior and perceived identity, for example on personal contexts, standards, beliefs, values, convictions, biases, and privileges.
The domains help structure reflection and facilitate comprehension rather than create isolated areas that confine reflection. In practice these domains are interwoven, and sometimes overlap. Labeling the domains provides vocabulary to enable comprehensive dialogue on what to reflect on.
The domains are depicted in Figure 1A.

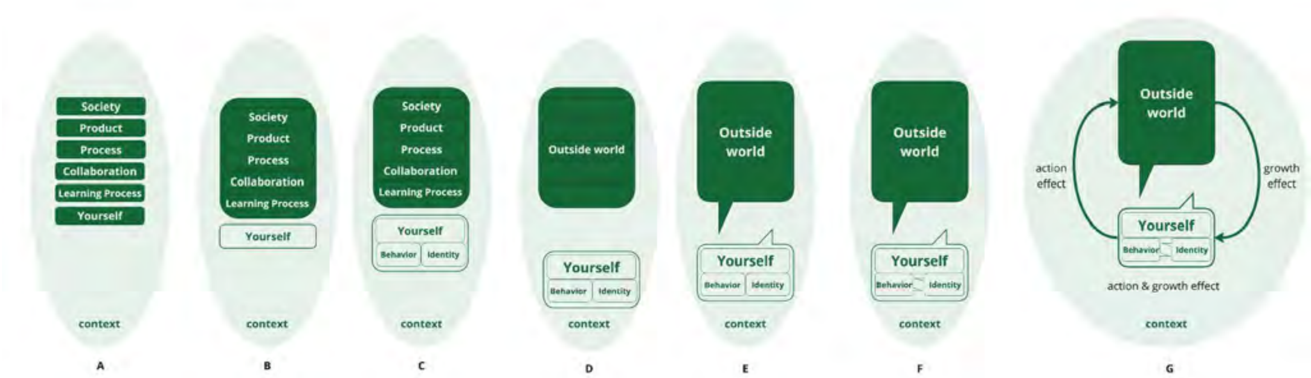

Figure 1 Visualization of (transformative) reflection

Element 3: Contextualization of reflection
Meaningful reflection happens in a context, not in a vacuum. As reflection needs to bridge the gap between the individual and their community it is important to be aware of knowledge, experience, mental models, interpretations, norms, culture, and values assigned to reflection by individuals, sections, departments, faculties, and educational programs that are present in the community. Leaders who prioritize reflection and create space for experimentation and for learning from failure foster a different environment than those who enforce strict control (Maarel 2016; Laloux 2016). For example, reflection on mistakes will be different in a department that frequently discusses mistakes, compared to a department that never discusses them. Finally, there are many practical context-dependent factors to take into account, as discussed above. These include, yet are not limited to, creating time, space, and a setting to create conditions for meaningful reflection to happen.

Element 4: Transformative reflection
Thirdly, we aspire to deepen reflection into *transformative* reflection. As mentioned before, superficial reflection is not uncommon, yet we aim for reflection that is able to initiate change, by contextualizing, enriching, and augmenting the reflective activity. The word 'transformative' is informed by the Oxford Advanced Learners' Dictionary that describes it as "causing or able to cause change", and by scholars like Kitchenham and Mezirow who have worked on transformative learning (Kitchenham

2008; Mezirow 2000) and contributions to the Journal of Transformative Learning, e.g. Minnes et al. (2018) and Scheele (2015). Based on these contributions we see transformative reflection as going through a process of reflection that is causing or is able to cause change in learners' points of view, frames of reference or habits of mind and how learners experience, conceptualize and interact with the world. Change can be small; for example, something suddenly making sense. Change can be big(ger); for example, a behavioral change is initiated. Transformative reflection can occur naturally or through a designated activity, yet not all reflective exercises we design for students are transformative (de la Croix and Veen 2018).

4 TRANSFORMATIVE REFLECTION IN PRACTICE

Transformative reflection cannot be forced, yet we find that we can design meaningful activities that create opportunities for this type of learning. We established three steps that need to be present in meaningful reflection activities.

Step 1: Distinguish and link multiple reflection perspectives
Figure 1B shows that our external reflection perspective is influenced by our internal reflective perspective. If we relate to or interact with the world, we always take ourselves with us. The external perspective is shaped by community expectations and outside requirements. Code-switching[3] (McCluney et al. 2019) is an example that demonstrates this principle. One consciously or subconsciously adapts one's behaviour to fit in different social or cultural situations. Figure 1C shows that the internal perspective consists of our perceived identity and our behaviour. Identity and behaviour may not always align and can vary depending on the situation. To design a transformative and reflective activity, it is important to incorporate both the personal perspective (ourselves) and perspectives that exist in the outside world.
[2] Code switching is the way in which a member of an underrepresented group (consciously or unconsciously) adjusts their language, syntax, grammatical structure, behavior, and appearance to fit into the dominant culture.

Step 2: Facilitate a dialogue between internal and external perspectives.
Understanding and seeing links between the six reflection domains and reflection perspectives is not enough. For reflection to become meaningful or transformative, we need a process that *facilitates an interaction* between ourselves and our perspective and the world outside of us: we create this interaction using the following four mechanisms.

Step 2.1: Create distance between ourselves and other domains.
First, we disentangle the domain of "Self" from the five other domains and create distance. By doing this we create the opportunity to define internal and external perspectives. Separating the internal perspective from external expectations creates space to consider multiple external aspects without the need to deal with them immediately. This also creates space to look at ourselves without expectations or judgements that are imposed by yourself or the world outside.

Step 2.2: Point out the gap between the internal and external perspectives and review each in isolation.
Now that we have created distance between the outside perspectives and ourselves, there is space to explore multiple possible interpretations or perspectives on the

issue at hand with a curious and open mind. Questions to explore include: what are the ways that other people regard the situation? How do other people or cultures deal with this? What are blindspots? What could be unintended side effects of choices made? How did the other person experience the collaboration? What other things could be learned in this course? Could there be different intentions than mine? Or: if I try to look at myself without judgment, what do I see? Mechanisms 2.1 And 2.2 are represented in Figure 1D.

Step 2.3: Create a 'dialogue' (tension) between inner and outer perspective.
Switching between internal and external perspectives creates a 'dialogue' which can provide a new perspective, or may provide insight into your position. This insight might change the way you perceived something previously. For example: suppose you were annoyed that one group member worked fewer hours than the others. By exploring reasonable causes of this behaviour, you might realize that there are many reasons for this behaviour to be acceptable, e.g. suffering a loss, being sick, taking care of family, having financial problems etc. This might not only give you a new perspective on the conflict, yet it might also give you some insight in that having no external responsibilities or no financial problems are a privilege that you enjoy. Subsequently, this insight might affect the way you handle a similar conflict; you might enquire with a person about the reasons behind it and be more empathetic. Going back and forth, adopting other views or perspectives, provides insight into the unknown parts of you or any blind spots (Luft and Ingham 1955) and it will change the way you relate to the outside world. This mechanism is represented in Figure 1E.

Step 2.4: Creating a second 'dialogue' between identity and behaviour
Transformative reflection requires a second dialogue between identity and behaviour. By examining and addressing the way we see ourselves in relation to our actions, we gain insights into our values, beliefs, and norms and/or in new ways to move forward. Building on the example of a group project conflict: the insight in that your work behaviour in this group is not only the result of your hard work, yet also of your financial and social circumstances might warrant the belief you are a 'hard worker', and it might also change the way you act when others are not pulling their weight. Or it might point you towards the realization you find it really difficult to act in such situations and that you need to work on your communication skills. This mechanism is represented in Figure 1F.

Step 3: Appreciate reflection for action and growth.
As the examples in the descriptions of the mechanisms illustrate, we differentiate between two reflection effects: reflection for action (What can I do differently?) and reflection for growth (What do I learn about myself or about how I see the world around me?) Taking time within the reflection activity to acknowledge the effect that the reflection has, supports consolidation of that effect. This mechanism is represented in Figure 1G.

5 DISCUSSION AND CONCLUSIONS

Today's wicked problems require engineers to be able to deal with the unknown and work across disciplines. This requires skills beyond the traditional boundaries of the engineering domain, such as social and ethical awareness, empathy and collaborative skills. Reflection is a prerequisite skill to those transversal skills, and

reflective skills enable engineers to notice and adapt to what is needed. Although reflection is widely regarded as important for engineers, its applications and the way it is taught generally has a narrow scope. Moreover, reflection skills are assumed to develop naturally. However, we found reflection requires structured attention, and specific instructional design.
We contextualize reflection as a tool in engineering and present prerequisites and mechanisms to design for deep, transformative reflection. Our approach complements existing reflection models. We attempt to initiate a fundamental change in how we design reflection in (engineering) education by moving towards emergence, instead of plug-and-play best practices. The six domains, perspectives and effects of reflection help engineering students and instructors understand how our perspectives influence how we relate to and influence the world.

Intuitively, the combination of reflection on the outside world to improve action fits well with engineers, as engineers tend to be analytical 'problem solvers', creators, designers and manufacturers. Contemplative reflection of the internal perspective for personal growth might be less intuitive, yet is crucial to develop proficiency in this skill (Hermsen 2022; Marshall 2019; Schön 1983).

We are aware many authors and practitioners already use elements of reflection we mentioned in this contribution. However, to our knowledge, there are no other publications that look at the contextualisation of reflection as a tool, or describe instructional design principles for transformative reflection. There might be other ways to design transformative reflection, yet the work presented here is our attempt to facilitate the process. The presented construct provides structure and key mechanisms for designing transformative reflection. However, it is not a foolproof step-by-step plan for designing effective reflective activities. Further experimentation with the model is needed.

The narrative feedback from students and instructors who participated in transformative experiential education is highly positive. They gain insights into themselves and others and see new ways forward and they value reflection higher. We are currently studying the impact of our transformative education in systematic ways. The work presented in this paper aims to raise discussion on the role of reflection in engineering education and leaves us to question how to scale up and make transformative reflection accessible to instructors.

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SUSTAINABILITY LEADERSHIP FOR THE ENERGY TRANSITION: A CASE STUDY OF ROLE-PLAYING TO ENHANCE AUTHENTIC LEARNING

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ABSTRACT

To lead the energy transition, effective sustainability leadership requires a spectrum of skills, knowledge and understanding across technical, financial and even political disciplines. An innovative, authentic learning initiative has been designed and implemented in which Master of Sustainable Energy students conducted team-based role-playing activities, responding to a realistic, hypothetical energy policy scenario in the form of a government announcement and other mock collateral. Groups were assigned the personas of a range of industry stakeholders and prepared presentations (and accompanying media statements and position papers) for a mock online media conference. The initiative leveraged the diversity of the cohort, enabling constructive interactions and an appreciation of the impacts of energy policy on a variety of organisations and wider society. Entry and exit surveys affirmed that participants gained a deeper understanding of key issues, constraints, alternative views and approaches involved in navigating the policy pathways to sustainability. The teaching staff also observed a high level of student engagement. Challenges of group dynamics and teaching effort were felt to be outweighed by the benefits reaped by students, particularly in terms of deeper conceptual knowledge and an understanding of perspectives in the energy transition. The case study also found that the online nature of the media conference enhanced student innovation and engagement. The framework of the case study may nudge other educators towards greater use of role-playing activities in sustainability leadership pedagogy.

1 INTRODUCTION

1.1 Sustainability Leadership in the Energy Transition

The transition to sustainable energy, as part of a global net-zero carbon future, can be characterized as a “wicked” issue, involving both conflicts and conciliation. Motivated and diverse leaders are required, adept in their ability to analyse, at disparate scales, the trade-offs between energy security, equity and sustainability. In this setting, a distinctive theory and practice of sustainability leadership has emerged (Shriberg and MacDonald 2013) This represents a more inclusive, balanced, and deliberate process of influence that aims to deliver direction, alignment, and commitment to address social, environmental, and economic issues (Bickley et al. 2013). The principles of sustainability leadership highlight the importance of cross-boundary networks and engagement with stakeholder perspectives, as well as systems thinking and facilitation skills to respond to complexity (Allen et al. 2014). Teaching these skills to new sustainability leaders who are involved in the energy transition requires innovative higher education pedagogies (Beagon et al. 2021) with a focus on authenticity and multiple perspectives.

1.2 Authentic Learning and the Use of Role-Play

Higher education curricula with a focus on sustainability leadership show a strong prevalence of project-based learning and the facilitation of interactions between participants (MacDonald and Shriberg 2016). This is often based on authentic, experiential learning, where participants are involved in realistic simulations that can be integrated into practice (Boud and Prosser 2002), and contextualised against delivered content and lived experience (Bartle 2015). When this is combined with group work, constituted by people with diverse backgrounds, the cross-pollination of ideas and concepts yields even deeper perspectives. The rapidly shifting landscape of the energy sector and sustainability requires knowledge and adaptable skills which are well suited to this pedagogical approach. Experiential learning coupled with the practice of reflection can cultivate deep and lifelong learning that contributes to professional practices (Ayers et al. 2020).

Role-playing is an authentic pedagogical approach identified to have high relevance for developing sustainability-related competencies (Gordon and Thomas 2018), required by graduates leading the energy transition. However, several challenges are associated with using role-playing activities, including the time required to design and deliver scenarios that both reflect the real world and engage students (Gordon and Thomas 2018). There is sparse research on role-playing activities in online and hybrid teaching settings.

1.3 Objectives of this Paper

This paper outlines a case study of a role-playing activity and its effectiveness in enhancing sustainability leadership skills. The context of the study is a course on Energy Markets, Law and Policy within the Master of Sustainable Energy, a unique multi-disciplinary program offered by the School of Chemical Engineering at The

University of Queensland. The course is delivered synchronously to both internal (on campus) and external (online) students via an intensive teaching period, followed by course assessment, including the team-based role-playing activity, which was conducted entirely online. The role-playing activity is centred around a fictitious, but credible, policy scenario, with students acting as organisations and responding via authentic channels such as media conferences and position papers.

Through anecdotal observations and longitudinal student surveys, the paper evaluates the efficacy of role-play across the dimensions of knowledge transfer, appreciation of complexity, competency to set energy policy, and consultative approach to stakeholder perspectives. The results of the case study show that the role-playing activity is very well received by students, encourages active participation and has been successful in upskilling in some of the key elements of sustainability leadership. The paper also reflects on the teaching effort required to coordinate the online activity, along with its challenges and opportunities, and provides some recommendations on its place in engineering education for sustainability.

2 METHODOLOGY

2.1 Role-Playing Activity Design and Implementation

Figure 1 presents how the program was conducted. Prior to the role-playing activity, students participated in lectures and workshops in an intensive format. In one lecture, external presenters delivered industry insights to their approach to energy policy. Students were assigned to groups by the teaching staff, with the diversity of team members being a key consideration. Each group was then assigned the persona of a distinct Australian organisation that is impacted by energy policy. They included an electricity generator, a hydrogen startup, a low-income advocacy organisation, a vertically integrated energy retailer and a think tank.

Students were provided with substantial collateral to explain the policy initiatives. The teaching staff invested substantial effort to produce mock content which replicated the format and limitations of real-world policy delivery. This included a short video announcement from the Prime Minister, a regulator's website, a branded capital raising prospectus and a ministerial press release. The materials had a consistent core message, but akin to real-world communications, the collateral contained gaps, inconsistencies and flaws. Together, the materials conveyed a hypothetical policy position to be adopted by the Australian government, which would have implications across the economy for investors, energy market participants, consumers and industry.

Groups were tasked to arrive at a position that supported the interests of their assigned organisation and stakeholders. The task required interpretation, analysis and persuasive response, conducted with an emphasis on leadership, teamwork and communication. Critically, the role-playing activity was held entirely online, via Zoom with all students present for the entirety of the activity. This facilitated a multi-perspective approach aimed at enhancing students’ sustainability leadership skills.

The role-play framework provided the scenarios for presentations and written content which constituted 50% of the students' total course marks, with an expectation that each student would contribute about 45 hours of work, although this was not monitored. Student submissions were generally of very high quality, reflecting the high engagement of the cohort and the competitive nature of group work, with some submissions exceeding teaching staff's expectations. Group deliverables were submitted two weeks after the intensive learning modules:

- A realistic, branded one-page media statement, submitted online before the presentation, and available to be read by all students.
- Submission of written well-formulated, tailored questions for each group, prepared as journalists.
- A 5-minute group presentation set in the style of an online media conference.
- A 5-10 minute response to questions.

In addition, two weeks after the media presentations, groups were required to submit a comprehensive Position Paper that further articulated organisational positions, and reflected on learnings from the presentations.

Non-presenting groups acted as the audience, role-playing as journalists attending the media conference, asking questions curated by the teaching staff. Later, groups were required to submit a position paper providing further details of the organisation's response to the policy announcement.

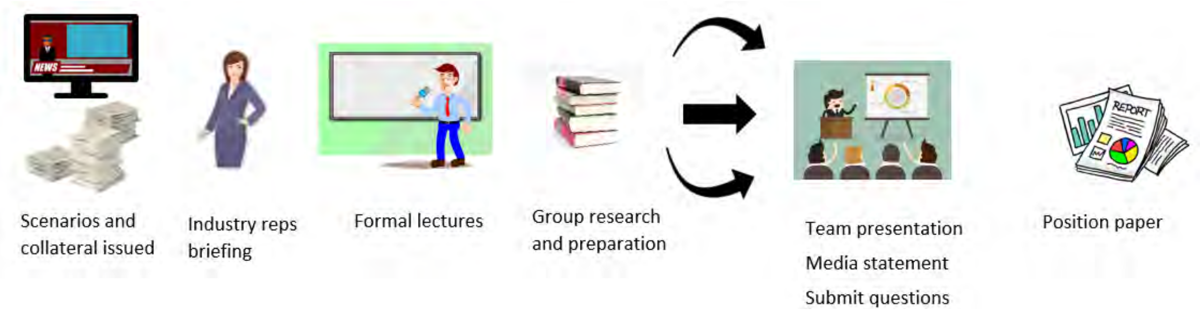

Figure 1: Learning initiative workflow

The primary learning objective of the role-playing initiative was to contextualize the core content of energy markets and policy. Secondly, students were trained in leadership through position development, team management and persuasive argument. And finally, students were afforded the opportunity to appreciate policy from alternative stakeholder perspectives. In the media presentations, groups were assessed using a marking rubric that covered all the deliverable outlined above. The Position Paper was also assessed, with further criteria on articulation of vision and references. To score well in the assessment items, a group's position required the appropriate use of facts, frameworks and underlying theories developed in the course. Groups were at liberty to agree or disagree with the proposed policies, or offer alternative policies and recommend methods for policy implementations.

2.2 Assessing Effectiveness of Learning Initiative

Direct observation, anecdotal feedback and survey instruments were used to establish if the role-playing activity enhanced sustainability leadership skills and achieved the objectives detailed in section 2.1. Positive attributes associated with experiential learning using role-playing (Boud and Prosser 2002) form qualitative and quantitative ways of measuring success.

Specifically, the assessment aimed to establish:

- Were competencies improved in sustainability knowledge and leadership?
- Did students' views about energy policy change as a result of the initiative?
- Did the initiative heighten students' engagement in the material?
- Did students value the role-playing and teamwork aspects of the activity?
- Was the learning experience compromised or enhanced by assigning students to role-play as organisations where sustainability values conflicted?

In order to assess the efficacy of the role-playing approach and to assess alignment with the project objectives, a longitudinal research approach was employed:

- A pre-course "entry" survey on content knowledge, attitudes to energy policy and leadership, using a 5-point Likert scale.
- A post-course "exit" survey consisting of the same questions, plus questions to understand changes in views, teamwork perspectives and values alignment.
- Anecdotal feedback from students and teaching staff.

Summary statistics from survey responses were derived to establish the degree to which students perceived that the learning objectives were met. A *t*-test was performed to determine the significance of changes in perceived competency upon entry and exit. Results were also segmented to determine if the cohort responded differently depending on domestic/international or full-time/part-time status. ANalysis Of VAriance was applied to establish if the survey responses were influenced by the ethical alignment between students and their organisation.

The surveys followed ethics protocols established by the Faculty of Engineering, Architecture and Information Technology at The University of Queensland. Participation in the surveys was voluntary, with clear information presented at the beginning of each survey explaining its purpose, the non-identifiable nature of any data/responses gathered and the right to withdraw from the project. The survey sought explicit consent from participants to use their data/responses for this research project. From a cohort of 60 students in 2022, 41 consenting responses were received to the pre-course survey and 31 to the post-course survey.

3 RESULTS

3.1 Student Survey Results

Content Knowledge, Attitudes to Energy Policy and Leadership

The student entry and exit surveys (Table 1) showed that the role-playing activity facilitated a vast improvement in energy policy content knowledge (Q1 - Q4). Sustainability leadership was manifest in increased confidence in 'knowing what to do' (Q6). All results were significant at the 95% level of confidence. There were no significant differences across domestic/international students or by full/part time.

Table 1. Student entry and exit surveys: self-assessment on knowledge and attitudes

(Entry N= 41), (Exit N=31). Scale 1 = Very Low to 5 = Very High	**MEAN ENTRY**	**MEAN EXIT**	**MEAN Change**
Q1. I judge my level of understanding on energy policy to be.	2.88	3.94	1.06
Q2. I know the aims of government energy policy in my jurisdiction.	3.02	3.97	0.94
Q3. I know how the government practically implements energy policy in my jurisdiction.	2.78	3.94	1.15
Q4. I understand how energy policy affects different parts of business/society	3.33	4.10	0.77
Q5. I can interpret energy policy announcements in my jurisdiction	3.10	4.13	1.03
Q6. If I personally held the responsibility to set energy policy in my jurisdiction, I would know what to do	2.51	3.74	1.23

Changes in Views

The exit survey asked students to quantify the extent to which their views on energy policy and regulation shifted as a result of their experiences during the course (Table 2). Students conveyed that the influence of energy policies extends to vastly more stakeholders in society (Q8), in a more complex manner (Q7), than they appreciated before the course.

Interestingly, responses were mixed on whether collaborative or authoritative energy policy approaches were better (Q9), with a bimodal distribution. The mean across *domestic* respondents for Q9 was 2.47 (indicating a shift to preferring more collaboration) while *international* students returned 3.47 (indicating a shift to a more authoritative approach), being a significant distinction at 95% confidence. This highlights the potential influence of culture, values and familiar government systems in forming views.

Table 2. Student exit survey: self-assessment on change in views through course

(N=31). Scale: 1 = Very Low to 5 = Very High	**MEAN**	**Stdev**
Q7. Compared to my views at the beginning of the course, I believe Energy Policy issues are less or more complex?	3.94	1.15
Q8. Compared to my views at the beginning of the course, I believe Energy Policy affects fewer/more stakeholders in society?	4.42	0.62

Q9. Compared to my views at the beginning of the course, I believe Energy Policy requires a more collaborative (1) or more authoritative (5) approach?	2.90	1.35

Teamwork and Role-Play

Exit surveys revealed the value that students placed on the role-playing and teamwork nature of the design (Table 3). The *effectiveness* response (Q10) indicates that students themselves discerned that engagement was elevated as a consequence of role-playing. The *importance* response (Q11) revealed that students recognised that the format of the initiative helped them to absorb content and acquire skills.

Table 3. Student exit survey: self-assessment on the importance of teamwork and role-play

(N=31). Scale: 1 = Very Low to 5 = Very High	**MEAN**	**Stdev**
Q10. How effective was role-playing as a learning approach to Energy Policy in this course?	4.16	0.73
Q11. How important was group work and role-playing to your learning outcomes in this course?	4.03	0.98

Values and Industry Involvement

Students were surveyed on exit to establish the degree of alignment between their personal values and the organisations that they role-played (Table 4). The positions and solutions that the groups promoted in role-play were generally aligned with their personal values (Q12), despite the fact that organisations included fossil fuel industry bodies and thermal electricity generators. The responses to Q12 and Q13 provided encouraging feedback that the emerging cohort of professionals is able to balance perspectives, including the roles of existing industrial stakeholders, as part of a sustainable energy future.

Responses to Q12 allowed us to investigate whether student engagement or other responses were systematically *lower* if students found themselves associated with an organisation whose values *disagreed* with their own. Application of ANOVA revealed there was *no evidence* of such dependence.

Responses to Q14 showed strong evidence that students would value ongoing access to a representative of their nominated organisation to guide decisions and interpretations. Our pedagogical design contemplated this feature, but for pragmatic and student equity reasons it was not instituted: it remains a possible learning enhancement in future.

Table 4. Student exit survey: self-assessment on values and industry involvement

(N = 31). Scale: 1 = Very Low to 5 = Very High	**MEAN**	**Stdev**
Q12. My personal values aligned with those of my assigned organisation/company	3.87	0.81

Q13. The position my group developed is an appropriate response for my assigned organisation/company.	4.35	0.75
Q14. How would you feel about the group project if there was a representative from the actual organisation available to answer some of your questions?	4.42	0.72

3.2 Student Anecdotal Review

Respondents offered free-text feedback on the exit survey and three main themes emerged (Table 5). Students verbally commented that the role-play was “a fun way to learn”, which was observed by the teaching staff, and supporting our assertions on student engagement.

Table 5. Student exit survey: Free text response examples

Theme	Example Comment
The role-playing format was an effective and engaging way to learn about energy policy.	*Role-play was an engaging and interesting method to discuss policy issues.*
Teamwork was a successful approach for sounding ideas and consolidating concepts.	*About the group presentation and role-play, it is a fantastic idea to engage the people with the Energy Policy. This is always a challenge because of the tough topic, and energy policy is not easy to digest and understand all the potential impacts that it could have.*
Viewing the presentations and preparing questions for other groups enabled an understanding of policy from different perspectives.	*It was good to put yourself in the company shoes then have to put yourself as a journalist to then think about questions and how the same policies affect other businesses.*

3.3 Reflections and Experiences of Project Designers

The teaching staff observed that the role-playing approach and relevance to real-world issues led to high student engagement and universal participation, which aided the teaching process. Deliverables were on par with professional standards, and the Zoom format allowed students to add flourishes, including costumes, microphone props, fake names, branding and background logos during their role-play.

Our assertions that students successfully contextualised sustainability leadership theory was based on the sophistication of responses formulated by students in presentations, both prepared and impromptu, and the way that reflections were weaved into the position papers.

Peer-based learning manifested through skills and knowledge sharing in group work, particularly supporting the less-prepared students. Group interactions reduced the volume of direct queries to the teaching staff.

However, some students provided feedback that the workload was burdensome, with high expectations. Group dynamics is always difficult in university environments, and some team disagreements were only resolved through intervention and alternative assessment paths. While disparate views added value in some groups, it could also result in irreconcilable conflict, presenting a microcosm of real-world climate politics.

Preparing the scenarios, collateral, managing groups and hosting role-play forums all add to the teaching workload. However, given the benefits to students and the positive outcomes it was felt that the initiative was worthwhile. Alternative ways of industry engagement have been documented (Thomson et al., 2021), but the balance between benefits and administrative burden is delicate.

4 DISCUSSION

Consistent with the finding of others (e.g., Gordon and Thomas, 2018), the authentic learning has proven successful as an initiative to enhance learning outcomes in sustainability leadership. The delivery model elevates student engagement, and role-playing itself acts as a training device to introduce skills such as presentation, communication and persuasive argument. The role-playing experience with authentic scenarios enables students to contextualise lived experience, contemporary current affairs and other course knowledge (Bartle, 2015).

Surveys measuring perceived competence illustrated a significant improvement in the cohort's energy policy knowledge and sustainability leadership. It is conceivable that content could still be reinforced with traditional delivery methods, but perhaps student engagement would be reduced, fewer conceptual connections would be made with the rest of the program, and real-world stakeholder perspectives would not be appreciated to the same extent.

The diverse organisations in the role-play exposed students to the vast complexity of the energy transition challenge. Entry and exit survey results confirmed significant changes in student views. Group work needs careful curating (Zou et al. 2012) and it was found some teams were unable to find conciliatory positions. Survey evidence suggests that ideological biases may be a contributing factor to group-work failure but longitudinal studies (Zou et al. 2012) suggest other pitfalls such as social loafing. Other teaching initiatives to foster teamwork (Azizan et al. 2018) have also found success as part of student-centred cooperative learning strategies.

It is worth reflecting on the limitations of role-playing. The tool simplifies complex sustainability challenges and decision-making, potentially affecting authenticity and the transferability of skills and knowledge (Kioupi et al. 2019). Role-playing activity that is executed poorly can be uncomfortable and emotionally overwhelming for some learners (Gordon and Thomas 2018) and can lead to scripted outcomes that reduce critical thinking. This study did not find any evidence of these issues, but the activity did benefit from well-prepared, realistic scenarios and collateral; a mature postgraduate cohort; and a mixed-methods approach to teaching and assessment.

Educators may encounter challenges integrating industry involvement in educational programs (Thomson et al. 2021). In this activity, it was found that corporations were protective of branding and reputation. When socialised, realistic student submissions were required to have watermarks and de-branding to ensure that they were not confused with actual corporate publications.

5 CONCLUSION

The generation of sustainability leaders who are presently emerging to guide the global energy transition has an enormous task ahead of them. To equip them only with technical and economic skills is doing a disservice to individuals operating in a highly cross-disciplinary field. This study has determined that role-playing delivers an authentic learning experience that successfully immerses students in energy policy, markets and regulations, and enables understanding and deep conceptual connections with other fields of sustainability. Importantly, the case study has shown that a multi-perspective approach can be delivered online efficiently, with high levels of student engagement and a high degree of authenticity.

While the initiative delivered successful learning outcomes, avenues for improvement have been identified. However, reflections suggest that enhancement of the resources and facilitation need to be balanced against the additional time and effort required. Future research could focus on addressing challenges including inclusivity and critical thinking, to maximise role-playing effectiveness in sustainability leadership education.

There are two main contributions emanating from our work. Firstly, the dissemination of this case study may contribute to greater consideration of the use of role-play as a rich and authentic learning experience in higher education. By documenting the approach of this case study and addressing the common perceptions of challenges and effort, the paper provides some insights to guide future educators.

Secondly, our implementation has documented the use of role-playing activities in an increasingly online, and/or hybrid learning environment. In the case study presented, the activity flourished across a student body constituted by teams who conducted group work in a hybrid format, including online sessions. While the role-playing activity itself was performed entirely online, no technical issues were encountered but some unexpected benefits were reaped in student engagement offered by the Zoom platform.

Together, these contributions may enhance the discussion on opportunities for planning and running role-play as a valuable activity for higher education in sustainability leadership. Indeed, the pedagogical approach and the assessment frameworks could be used by others to assist with more widespread implementation of this worthwhile activity.

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HELP – Home Electronics Laboratory Platform –Development and evaluation

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Conference Key Areas*: Engineering Skills and Competences, Lifelong Learning for a more sustainable world, Innovative Teaching and Learning Methods*
Keywords*: Engineering laboratories, take-home laboratories, independent learning, troubleshooting*

ABSTRACT

In response to the COVID pandemic, many of our undergraduate students were supplied with custom development kits to undertake their electronic laboratory activities at home. Following our return to on-campus teaching, we plan to combine on-campus laboratory sessions with at-home experiments taking advantage of both on-campus and at-home experimental work while avoiding some of the limitations experienced during remote teaching. The goal is to embed active learning as a key part of a long-term strategy to enable students to better manage their learning and to maximise the analytical engagement with lecturers in a hybrid blend of on-campus and remote activities.

In this paper, we report on three generations of the at-home laboratory kit developed by the author's institute and partners in the Erasmus+ project "Home Electronics

Laboratory Platform (HELP)”. The HELP kit comprises a portable signal generator and measurement instrument and a custom electronic board, which includes several functional blocks alongside the usual breadboard for assembling circuits with discrete components. The motivation for the design of each generation is introduced and the desired functionality and its implementation are described.

The impact and user experience with the kits have been assessed through student surveys and staff focus groups in the HELP consortium partners. The main themes associated with take-home electronics laboratories have also been explored in a workshop with HELP partners and contributors from other universities across Europe and the USA. This work is summarised and future potential technical and pedagogical developments are outlined.

1 INTRODUCTION

Fundamental undergraduate courses in electronics require practical experiments building and characterising circuits using laboratory equipment. This experience is crucial because it allows students to acquire essential skills such as setting up and conducting an experiment, using specialised equipment, testing, debugging, data interpretation and documentation. In our curriculum and teaching practice we seek to design our laboratory practice to achieve the 13 ABET objectives for students completing a laboratory series in an engineering undergraduate programme (Feisel and Peterson 2002) as listed in Table 1.

ABET Objectives	
Instrumentation	Creativity
Models	Psychomotor
Experiment	Safety
Data Analysis	Communication
Design	Teamwork
Learn from Failure	Ethics
Sensory Awareness	

Table 1 ABET Undergraduate Engineering Laboratories Objectives

After reviewing our traditional pre-COVID practice we determined that to achieve these objectives more laboratories should focus on providing opportunities for students to develop their own solutions, providing more design opportunities, involving formal collaborative learning and including a more explicit focus on health, safety and the environment. Laboratories that adopt enquiry, problem or project-based approaches are good candidates to improve alignment with desired outcomes such as the ABET objectives (Vesikivi et al. 2020).

The dominant approaches to laboratory practice have been in-person, simulation-based or remote laboratories. Existing research has explored ways of doing each along with their relative advantages and limitations, (Corter et al. 2011; Brinson 2015)An alternative to these three modes of delivery is the take-home laboratory which has received little attention within the engineering education research literature. A take-home laboratory (also called a distance laboratory) can be defined as an educational laboratory where students perform hands-on experiments with physical devices in their own homes.

In this article, we describe the development of take-home laboratory equipment for electronic engineering students in response to the COVID-19 pandemic. The kit has subsequently been developed to explore enhanced delivery using a blended laboratory teaching approach. Students are sent a bespoke low-cost Home Electronics Laboratory Platform (HELP) platform consisting of a combination of off-the-shelf portable test tools and a custom circuit board where students could perform typical laboratory activities. Following the success of the take-home system during COVID-19 teaching an ERASMUS+ EU project (HELP) was funded to further develop new application-driven versions of the platform. The HELP platform is open-source and so can be easily replicated within other institutions or purchased for a low cost. It can be used to enable learners to develop a rich understanding of core concepts associated with Electronic and Embedded Systems Engineering.

It can also expand access to engineering education for disadvantaged learners due to its low cost and flexible learning approach. For online and distance learning environments, low-cost take-home laboratories can increase student enrolment, help motivate learners and develop practical skills (Kennepohl 2017). This richer understanding also impacts more traditional in-person environments as take-home laboratories can be used to realise project-based experiences which have been shown to positively impact learning and enhance student retention (Vesikivi et al. 2020).

In this paper, we report on three generations of the at-home laboratory HELP kit developed by the author's institute and partners We draw on our experiences to discuss some potential applications of the current system and explore the potential for further development.

2 TAKE-HOME LABORATORY DEVELOPMENT

The traditional, on-campus, laboratory is a key element of conventional teaching and learning engineering subjects. In our programmes, 40-60% of student contact hours are allocated to application classes (lab/project). For electronics, this typically involves weekly application classes with activities focused on circuit analysis and characterisation through simulation using SPICE-based programs and by performing experiments on well-defined test setups assembled by students during the lab class. Typically, these activities require a set of standard laboratory equipment (power source, signal generator, oscilloscope, multimeter and breadboard as shown in Figure 1), and a set of electronic components, wires and connectors. This equipment is most often set up in a laboratory class with students timetabled to have 2 hours of practice time per module in the laboratory each week to carry out the required circuit experiments.

There is limited published literature on take-home laboratories with reported developments to support a variety of subject areas including mechatronics (Stark et al. 2013), fluid mechanics (Meng et al. 2018), mechanical engineering (Schajer 2021), control systems (Jouaneh, Boulmetis, and Palm 2013), embedded systems (Kommu, Uttarkar, and Kanchi 2014), digital electronics (McCarthy, Murphy, and Popovici 2022; Oliver and Haim 2009; Ruo Roch and Martina 2022) and communications (Popović et al. 2020). In the majority of these papers, the focus is on describing the kit and then describing some typical experiments to outline its use and there is little reporting of data-driven development of the kits after initial deployment.

Fig. 1. Typical laboratory setup for an undergraduate electronics laboratory

Topic	Required features	Measurements	HELP
Embedded Systems development VHDL	Advanced microcontroller FPGA		
Embedded Systems Basics	Basic Microcontroller	AC Values Timing signals	V2.0
Analog integrated amplifiers Sensor interfacing Transistors Amplifiers ADC/DAC converters	Bipolar power	AC Values Timing signals	V1.1
Sequential Digital circuits Passive AC circuits Active AC circuits	Clock signals AC signal source	AC Values Timing signals	V1.0
Combinational Digital circuits Passive DC circuits Active DC circuits	Digital I/O DC Supply Variable voltages	DC values	V1.0

Table 2 Progression of required circuit experiments in undergraduate electronic engineering

2.1 HELP V1.0

The HELP V1.0 kit presented in Figure 2 was developed in response to the Covid19 pandemic. It consists of a compact, standalone 3-in-1 handheld instrument - the Hantek 2D42 portable scope ("Hantek 2000 Series Product Description" 2023) - and a USB-powered electronic board, designed specifically for this purpose. The Hantek 2D42 instrument provides an Oscilloscope able to monitor two channels for frequencies up to 40MHz, an Arbitrary Waveform Generator (AWG) able to provide sine- and square-waves with programmable frequency (up to 1MHz) and amplitude (up to 2.5Vpk), as well as a Digital Multimeter.

Fig. 2. HELP kit V1.0 laboratory board and board in carry case with Hantek 2D42

2.2 HELP V1.1

The HELP V1.1 kit presented in Figure 3 was developed to address usability issues encountered with HELP V1.0 and to also add additional functionality to expand the range of experiments that students could carry out as shown in Table 2. The Hantek 2D42 was upgraded to the Hantek 2D72 as this part had more parts in stock and this provides an Oscilloscope able to monitor two channels for frequencies up to 70MHz.

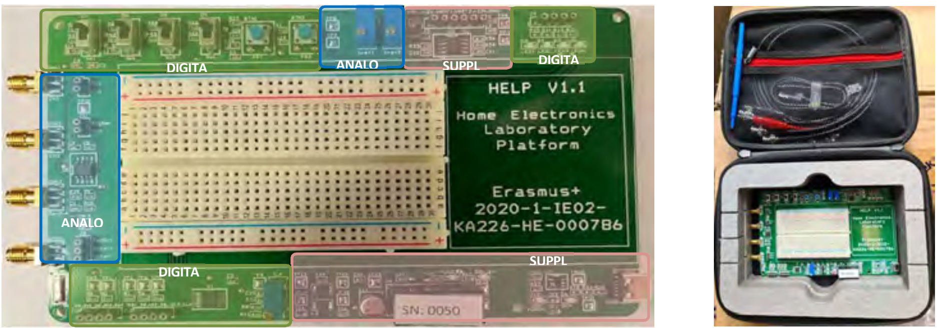

Fig. 3. HELP kit V1.1 laboratory board and board in carry case with protective foam

As with HELP V1.0, the V1.1 kit includes the breadboard, required wires and cables for all experiments, and the HELP PCB which also includes several functional blocks implemented on-board that expand the range of experiments students can perform. The main additional features are:

- symmetrical supply lines, ±12V
- power amplifier able to scale up the signal provided by the Hantek instrument, to an amplitude of maximum 10Vpk for the sinewave.
- DC voltage sources with values adjustable manually between ±10V
- digital clock generator, with frequency adjustable from 0.3Hz to 210Hz
- several switches and push buttons (both straight and debounced) to generate logic inputs and LEDs to monitor logic states.

Figure 4 presents the block diagram of the HELP V1.1 board. The functional blocks are grouped in three sections: the power supply section, the analog section and the digital section.

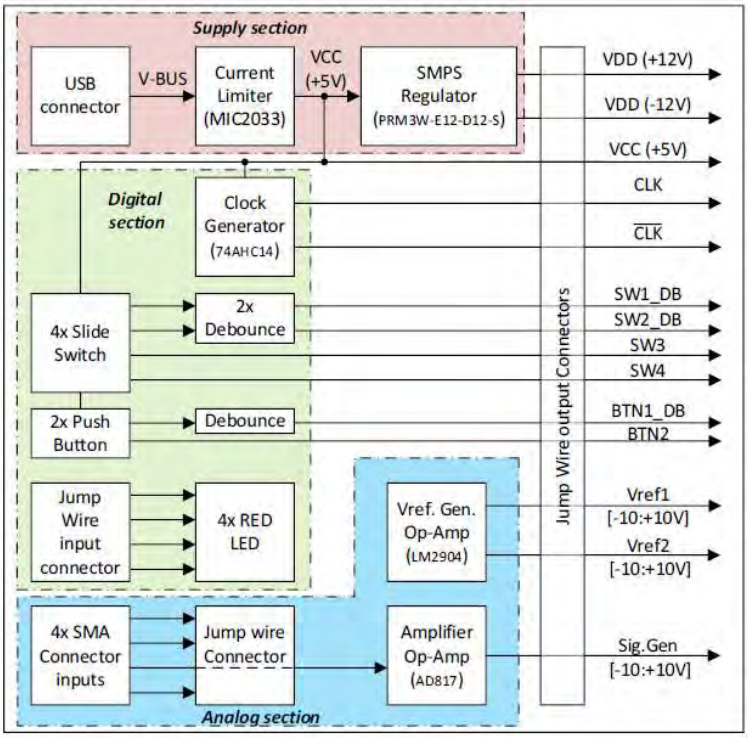

Fig. 4. Schematic of the Helpkit V1.1 electronic Board

2.3 HELP V2.0

The HELP V2.0 kit, presented in Figure 5, was primarily developed to reduce dependence on the Hantek 3-in1 instrument which was increasing in cost and restricted options for potential users. HELP V2.0 was developed to have an integrated Arbitrary Waveform Generator (AWG) able to provide sine- and square waves. The inclusion of this feature was accomplished using an Arduino Nano controlling an AD9833 Programmable Waveform Generator. The Nano board provides additional functionality expanding the range of experiments that students could carry out to include basic microcontroller programming as shown in Table 2. The kit now requires an external oscilloscope and multimeter but many institutes will have invested in such portable measuring equipment and can use the HELP kits without incurring any further cost. HELP V2.0 includes the Help Kit V1.1 electronic board functions and in addition, includes:

- Onboard Signal generator: Arduino Nano, Display, Rotary encoder
- Arduino Nano pins available for coding

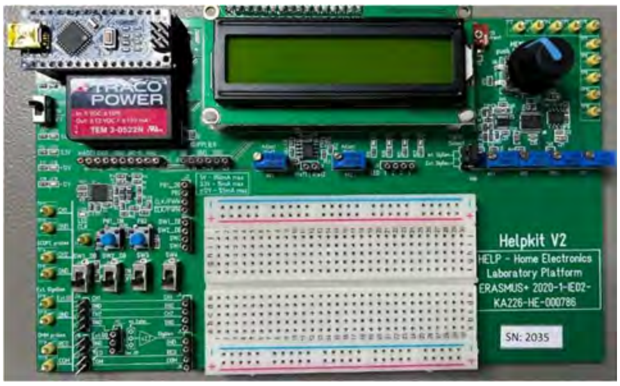

Fig. 5. HELP kit V2.0 laboratory board with the same dimensions as V1.1

The system schematic for V2.0 is shown in Fig 6. The supply section uses a different chipset with increased performance and power consumption limited to 2.5W from the 5V USB supply. The digital section has the same switch inputs and LED outputs as V1.1 but has additional ADC and PWM lines available from the Arduino Nano. The system clocks are also generated from the Arduino Nano which configures the output from the AD9833 Programmable Waveform Generator in the Analog section and amplifier gains from the generated AC signals.

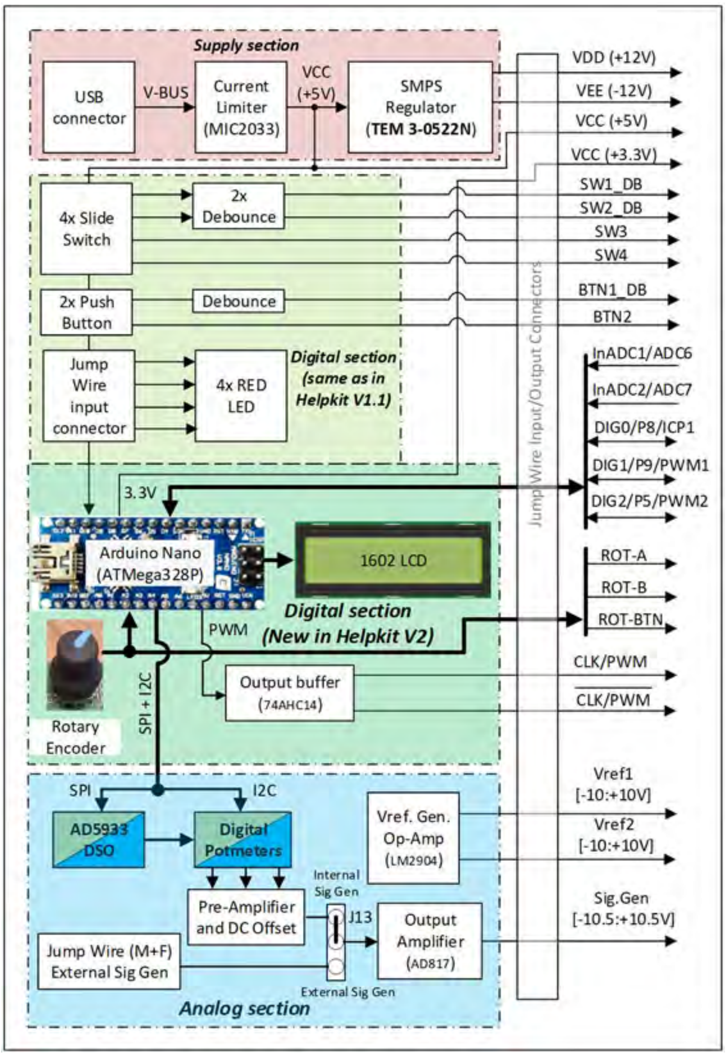

Fig. 6. Schematic of the Helpkit V2.0 electronic Board

3 RESULTS

The HELP kits have been developed and deployed over the past 6 semesters and we have tried to evaluate their impact and based on that data evolve the kit and our teaching practice to better meet the desired learning objectives for our students in laboratory sessions. In this section, we report on some of the feedback from HELP kit users and explore some possibilities for future development of the HELP kit.

3.1 Evaluation of HELP kit

The HELP kit has been used by students in several university programs at different stages of undergraduate development. Feedback on the experience of students and lecturing staff (O Mahony et al. 2022) has been gathered via surveys and focus groups. Initial feedback from learners gathered via surveys has been positive. As shown in the results of one survey presented in Fig 8, students were very positive about the lack of time constraints in completing tasks and also reported a high level of peer support in completing the experimental tasks. Relative to the on-site laboratories, the students found the more independent nature of the learning challenging and many experienced a lack of focus.

In a blended laboratory approach, the laboratory practice in pilot modules has been modified to include an increased portion of project-based activities. This involved restructuring the module activities from 100% directed exercises to a hybrid approach with 40-100% project-based activities. Modules, where students are introduced to new concepts, experimental setups, and measurements, include a higher proportion of directed learning in the early stages of the module. Student feedback has also been positive in this development.

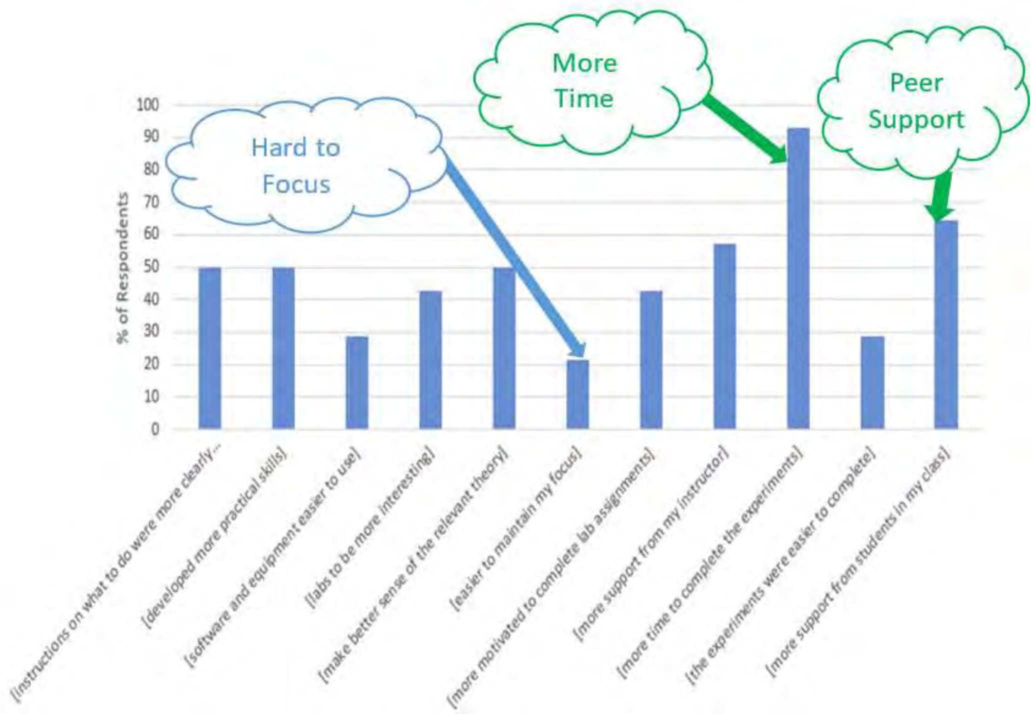

Fig. 8. Initial student feedback on HELP Take-home Laboratories

3.2 Future Development

HELP V2.0 has expanded the range of laboratory activities that can be supported with at-home delivery from our initial development as shown in Table 2. The Table also highlights those areas where undergraduate students will require additional equipment to meet their circuit design and embedded systems development laboratory needs. Future HELP developments could address the following topics:

- Cost reduction – the requirement for a two-channel oscilloscope with HELP V2.0 adds significantly to overall system cost and size for portability. The current cost for a full HELP kit is approximately €250 and this may be too costly for large scale deployment. A target cost would be to reduce this price by 50%. This could be addressed by adding a built-in oscilloscope on the HELP board with a software interface via the USB port.
- Added functionality – The kit could add FPGA and higher-power microcontrollers to the design to allow for laboratory exercises using these systems to be completed. These components could be used to develop the in-built scope function. This would make the system more complex and could reduce the simplicity of use that is attractive to students in their early years.
- Modify laboratory practice and assessment to encourage independent and collaborative activity enabled by take-home kits.
- Expand the online peer and tutor supports available to assist students and avoid excess time in troubleshooting or the associated lack of focus.

4 SUMMARY AND ACKNOWLEDGMENTS

Three generations of the at-home HELP laboratory kit which comprises a portable signal generator and measurement instrument and a custom electronic board for circuit and embedded system experimentation have been presented. The learning objectives of electronic laboratory practice have been outlined and the motivation, functionality and application level of each generation is described.

The impact and user experience with the kits has been assessed through student surveys and staff focus groups. The main benefit reported by students was increased experimentation time while the main problem encountered was in troubleshooting in the absence of tutor support. The take-home experience has been positively received by staff and students and future potential technical and pedagogical developments were outlined.

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ESTABLISHING A TIMBER-FOCUSED COMPETENCY FRAMEWORK TO UP- AND RE-SKILL BUILT ENVIRONMENT PROFESSIONALS TO MEET SUSTAINABILITY GOALS

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ABSTRACT

Engineers equipped with skills for a sustainable built environment have never been more critical, as government and industry sustainability goals such as the 2050 net zero target have significant implications for the construction sector. Concurrently, the UK's Construction Industry Training Board (CITB) has estimated that over 250,000 new workers will be needed by 2027 to meet demand. Besides this need for green skills, the sector is also looking towards more sustainable building materials, methods, and technologies, such as homegrown biogenic offsite manufactured (bio-OSM) timber: an innovative technology requiring additional engineering and manufacturing expertise.

To address this critical skills gap, the Timber Technology, Engineering, and Design (TED) Competency Framework was established by a coalition of academic and industry partners. This framework then informed the development of a hybrid training course that can prepare the next generation of timber engineers with the knowledge, transferable skills, and industry experience that can drive change towards sustainability in the built environment and inform a transformational approach in engineering education.

This practice paper describes the development of the Timber TED framework and the launch of the corresponding training programme in September 2022. It also reflects on the initial implementation across two cohorts, delivered at the Centre for Advanced Timber Technology at the New Model Institute for Technology and Engineering in Hereford, England, in partnership with Edinburgh Napier University and Timber Development UK. This educational initiative showcases an innovative and replicable approach to upskilling and reskilling for green skills in engineering education.

1 INTRODUCTION

80 to 90% of our time is spent in the built environment, with buildings and construction together accounting for 36% of global final energy use and 39% of energy-related carbon dioxide (CO_2) emissions (Timber Development UK 2023). With 300,000 housing starts called for by the UK government per year (UK Parliament 2022), building materials and technologies that promote sustainable and regenerative practices are essential to achieving net zero. The utilisation of modern engineered timber products like cross-laminated timber (CLT) from sustainably managed forests capture carbon and store it in the built environment resulting in an additional 1,556 to 2,567 t CO_{2e} stored in the structure of a hybrid CLT building compared to a traditional reinforced concrete building (Pierobon et al. 2019). Indeed, the embodied carbon of a house constructed using offsite panellised timber frame is approximately half that using traditional masonry forms (Monahan and Powell 2011). Timber buildings are also capable of meeting performance targets including Passivhaus Standards with high levels of airtightness and thermal and energy performance, and they can be produced efficiently using modern methods of construction that minimise waste.

However, the UK is one of the largest global net importers of timber products, creating emissions from shipping and limiting local economic growth potential from local forest resources. Of these imports, 42,500 m3 / year is of CLT. At present there is no UK commercial producer of CLT, although it has been demonstrated to be feasible (Crawford, Hairstans and Smith 2013). Scaling up the production of homegrown CLT would represent a viable way of increasing the 30% utilisation of UK produced sawn softwood in construction, estimated to be 3.6 million m3 per annum (Construction Management 2015). Besides homegrown mass timber, other advanced timber technologies can also positively impact sustainability goals by responding to the need for restoration and retrofit. Digitisation is unlocking the potential of these materials and systems, and it is also considered a game changer in the construction sector with the implementation of Building Information Modelling (BIM), the integration of Enterprise Resource Planning (ERP), the utilisation of Virtual Reality (VR) and Augmented Reality (AR), and Digital Twinning. The opportunity is a digitally connected ecosystem of built assets with a digital thread from these back to the forest floor implementing a virtual factory environment capable of improving overall productivity, maximising resource utilisation, unlocking investment and creating sustainable growth.

Yet to take advantage of these advances, the construction sector must address its skills crisis. Engineers from multiple disciplines – materials, manufacturing, civil, and structural – are needed who possess the knowledge and skills that can catalyze efforts around these opportunities for positive impact. Besides requiring more workers with new skills, the industry must change culture towards more collaborative and interdisciplinary approaches (Fort and Cerný 2022). This means new and different ways of working, requiring but also enabling flexible, hybrid learning with opportunities to engage with real world challenges, clients, and companies.

2 METHODOLOGY

The method adopted to address these needs was multistaged constructive alignment focused around three strategic actions. A constructive alignment approach was chosen because it enables a holistic educational strategy that provides a throughline between policy, learning outcomes, and pedagogy (Loughlin, Lygo-Baker and Lindberg-Sand 2020). First, a Competency Framework was developed through an iterative process of stakeholder engagement as part of a Timber Industry-approved Skills Action Plan (Timber Development UK 2023). This framework then informed learning outcome development for an educational programme mapped to those competencies. Finally, two short hybrid courses based on this programme of learning were developed for postgraduates and working professionals.

2.1 Timber TED Competency Framework

Competency frameworks are common across many industries, and they have become increasingly pertinent to sustainability education efforts; for example, EU GreenComp sets forth 12 competencies to foster a sustainability mindset through knowledge, skills, and attitudes, and the Institute of Environmental Management and Assessment articulates the sustainability skills and knowledge required at different career stages. Competency-based approaches to education have been employed since the 1960s (Nodine 2016) but have gained wider attention in engineering education in the last two decades (Henri, Johnson and Nepal 2017). Scholars have shown that these frameworks are essential for developing programmes of learning that can support future leaders and positive change within sustainability education (Lozano et al. 2017).

Professional competencies are also viewed as crucial within the UK construction sector, and the Chartered Institute of Building (CIOB) has made clear that significant up- and re-skilling in these areas is required for the 3.1 million people employed in the UK construction sector (CIOB N.d.). Indeed, in 2020, the British Standards Institution also announced the development of an overarching framework for competence in the built environment sector.

Technical competencies are essential for built environment practitioners; however the education of future engineers also requires the instillation of collaborative practices, leadership development, improved holistic understanding of the net-zero challenge, and meaningful and valuable work experience with an emphasis on SME engagement.

Against this backdrop, experts at Edinburgh Napier University, with funding from the HCI Skills Gateway, established a stakeholder group of all the main UK timber industry bodies, including the Structural Timber Association, the Confederation of Forest Industries, Swedish Wood, Truss Rafter Association, Timber Trades Federation, and Timber Research and Development Agency (the latter two now having merged to form Timber Development UK, or TDUK). These networks gave access across the interface of UK and European construction and timber sectors to consult and inform on establishing a framework with core competencies in timber relative to industry occupations and level of necessary attainment.

The development of the framework was an 18-month process which began with desk research using a range of sources, from job descriptions to existing relevant competency frameworks and chartered member requirements. Following desk research, interviews with key sector stakeholders enabled the drawing up of a first draft of the framework that was presented to working group members for discussion and feedback. Further revisions were made and additional content was developed and refined. Feedback was then obtained at two events: the Timber Engineering and Design Steering Group meeting and the Offsite/Mass Timber Construction Virtual Conference. After a subsequent review by the working group, wider views on the structure and content of the framework was sought through an industry survey.

The resulting Timber Technology Engineering and Design (TED) Framework consists of three competency areas: 1) core technical competencies; 2) cross-disciplinary competencies; and 3) core behaviours and meta skills. The competences are designed to be at English, Welsh, and Northern Irish Levels 5-7 and Scottish Levels 8-11 (equivalent to HNC/D – degree level). They assume foundation knowledge in maths, English, physics, and/or chemistry, according to job role. A depiction of the framework can be seen in Figure 1.

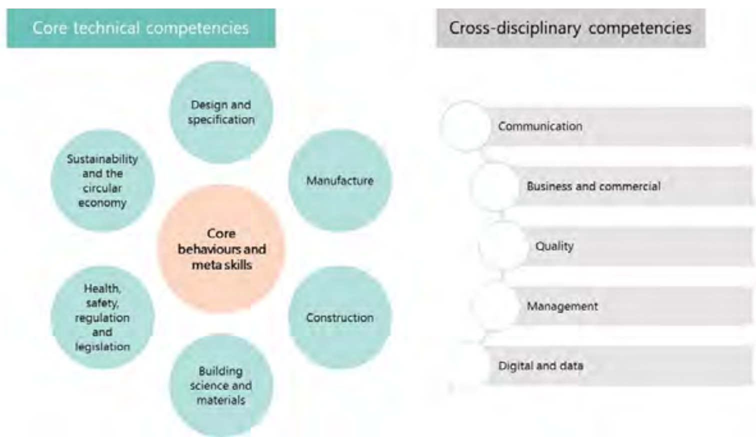

Fig. 1. Competencies Identified in the Timber TED Framework

The framework outlines specific content in each technical competency area, referring to technologies, processes, materials, systems, and standards that enable practitioners to maximise a globally responsible approach to timber construction. Six core behaviours and meta skills are identified that sit at the centre of all competency development and must be fostered alongside the technical knowledge, without which its implementation would be impeded. These are: Critical thinking and problem solving, Innovation, Collaboration and teamwork, Organisation, Professionalism and career development, and Ethics.These competencies speak to the durable, transferable skills essential to interdisciplinary and inclusive work. They spur the ability for judgement, creativity, initiative, reflection, and lifelong learning which is applicable to professional, academic, and civic life. Finally, cross-disciplinary competencies are articulated which reflect the knowledge and skills that then enable the technical competencies and core behaviours to combine for optimum capability development as well as for delivery of the sustainable built environment.

Taken together, the competencies outlined in the Timber TED Framework are designed to help learners put technical principles into practice in an effective and responsible way. Crucially, they move beyond a focus on solving technical problems and explicitly call for the development of knowledge, skills, and behaviours that reflect the broader environmental, social, and economic impacts that built environment professionals must acknowledge and grapple with. They are written so that they could easily be adapted into learning outcomes or performance standards within many engineering disciplines, meaning that they have relevance to students, educators, professionals, accreditors, and employers.

2.2 Course Development and Framework Implementation

The Centre for Advanced Timber Technology (CATT) at the New Model Institute for Technology and Engineering (NMITE) in Hereford, UK, was established in 2021 in partnership with Edinburgh Napier University (ENU) and TDUK to be a centre for timber engineering excellence and to drive the change towards new ways of building, learning, and working. In response to the development of the Timber TED Competency Framework, CATT educators developed a comprehensive and flexible training programme in partnership with TDUK. The programme is comprised of 2 hybrid short courses, TED 1 and TED 2. TED 1 focuses on learning outcomes necessary to understand timber as a structural material, the array of product options, and how they can be used to respond to a design brief sustainably. TED 2 builds on this by creating a broader understanding of timber in construction and design for manufacture and assembly approaches including available technologies. Learners gain specialist knowledge and skills for ‘better, faster and greener’ built environment delivery. Grounded in immersive ‘learning by doing’ activities, Timber TED stimulates critical thinking and instils new knowledge and skills to achieve net zero carbon. Both courses are delivered over 12 weeks and consist of three modules: a design module featuring a real-world challenge running for 12 weeks, and two complementary modules running for 6 weeks each in sequence. While the majority of learning takes place online, learners are brought together for three 3-day residential blocks where they engage with local partners, work in teams, and present their projects. To illustrate this structure, Figure 2 shows the delivery and content of the TED courses.

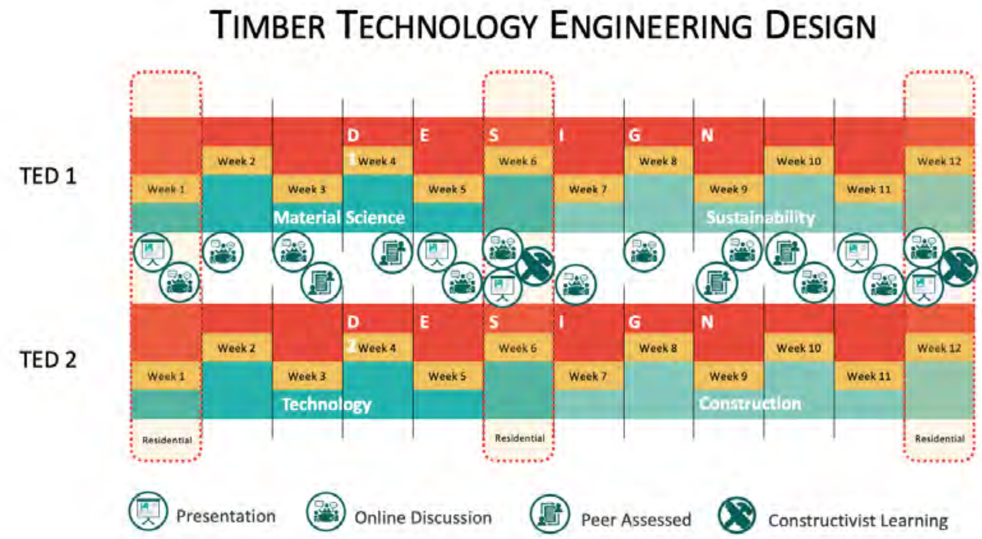

Fig 2. A visual depiction of the TED course structure

3 FINDINGS

Each strategic action has resulted in a key outcome. First, the Timber TED Competency Framework was endorsed by industry and formally released as part of a Timber in Construction Skills Action Plan in December 2022 which called for training and development in timber technical knowledge and core skills to help achieve net zero carbon. Second, the TED educational programme was approved by Chartered Institute of Architectural Technologists as a continuing professional development course, and approval is in process with the Construction Industry Training Board. Finally, the Timber TED short courses were launched at CATT in Sept 2022 in partnership with local employers Oakwrights, Taylor Lane and Border Oak as well IBI Group, Fast House and Stirling Prize Winning architectural practice dRMM and Wood Award Winner Stage One. So far, 24 learners (42% female) have undertaken TED 1 over two cohorts (September 2022 and January 2023), and the first iteration of TED 2 began in June 2023 with 11 learners participating. The learners represent many different roles and industries, including architecture, design, engineering, and sales. This allows for a multidisciplinary learning environment, enabling a more holistic approach to problem solving.

Stakeholder feedback has been collected via surveys of learners and industry partners, and it has been overwhelmingly positive. Learners particularly appreciated the experiential opportunities such as a productive forestry walk and sawmill visit, and the introduction to new skills and technologies such as timber grading and 3D scanning. Comments from the surveys include:

Quote from learner: " I believe that courses such as TED 1 offered at NMITE are required by the industry if we hope to diversify our knowledge of more sustainable construction materials and methods to reach our Net Zero 2050 ambitions."

Quote from Industry: “we need to attract into our industry the next generation, educate and train them well so that they can grow quickly into the driving force for the use of wood and all the advantages to global warming the greater use of timber brings."

These testimonials demonstrate how student demands and industry needs can collectively inform an approach to sustainable engineering for the built environment.

However, a more robust assessment approach is required to ensure alignment with the Timber TED Framework, provide guidance on continuous improvement, and inform other initiatives such as accreditation and industry recognition of professional development. Additionally, further work must be done to connect these efforts with other areas of the built environment sector. As emphasised by the report *Modernise or Die* (Farmer 2016), construction culture is broken and there is a need for improved levels of collaboration with disciplines working together to create sustainable solutions.

4 NEXT STEPS AND SUMMARY

While initial efforts have been focused on the competency framework development and the corresponding educational delivery, the next crucial component is to enact an assessment approach. This will be achieved through tools created by the Housing Construction Innovation Scotland – funded organisation Daydream Believers. In July 2023 the usefulness and transferability of their STAMP iT and STELLAR assessment tools will be employed to provide quality evaluation of the Timber TED courses and learning. A corresponding assessment activity will correlate Timber TED efforts to the CIOB Corporate Plan 2023-28 which aims to bring about cultural change that ensures quality and building safety are never sacrificed for profit and equips modern professionals with the knowledge and skills necessary to delivery construction processes in environmentally sustainable ways that also champion diversity, inclusion, and worker welfare. Further, a multi-stakeholder leadership group for timber industry skills will be established, and an open access knowledge library of timber information is being created that can be used across sectors including within engineering education. Finally, a delivery model via regional hubs across the UK is being trialed as a means for upscaling and reaching more learners.

Indeed, the innovative educational approaches adopted within the Timber TED courses (hybrid delivery, challenge-based, real-world scenarios, working in diverse teams) for the purpose of achieving the Timber Skills Action Plan could easily translate to other areas of engineering education beyond timber and beyond the built environment and serve as a model for other industries and disciplines.

Ultimately, the hope is that sustainable skills development within the built environment can in turn inform the development of more sustainable policies. When engineers are competent in the knowledge, skills, and mindsets required for responsible and regenerative design and delivery, they can develop the confidence to advocate for a better future for people and the environment.

The development of the TED1 and TED2 courses, with learning outcomes aligned to the Timber TED Competency Framework's professional skills and capabilities, demonstrate a method that could be replicated to encourage innovative engineering education that meets the need for sustainable engineering practice.

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INTEGRATION OF AGILE DEVELOPMENT IN STANDARD LABS

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ABSTRACT

In addition to the technical content, modern courses at university should also teach professional skills to enhance the competencies of students towards their future work. The competency driven approach including technical as well as professional skills makes it necessary to find a suitable way for the integration into the corresponding module in a scalable and flexible manner. Agile development, for example, is essential for the development of modern systems and applications and makes use of dedicated professional skills of the team members, like structured group dynamics and communication, to enable the fast and reliable development. This paper presents an easy to integrate and flexible approach to integrate Scrum, an agile development method, into the lab of an existing module. Due to the different role models of Scrum the students have an individual learning success, gain valuable insight into modern system development and strengthen their communication and organization skills. The approach is implemented and evaluated in the module Vehicle Systems, but it can be transferred easily to other technical courses as well. The evaluation of the implementation considers feedback of all stakeholders, students, supervisor and lecturers, and monitors the observations during project lifetime.

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1 INTRODUCTION

Including practical training of professional skills into existing modules is rather challenging and many different teaching strategies were developed with different emphasis on problem or project based learning, online and offline activities or active learning (Fitzgerald and Lentmaier 2016, Aluvalu et al. 2017). Problem or project-based learning (both abbreviated with PBL) or cooperative learning are commonly used methods to combine technical and non-technical content (Fedorinova et al. 2018, Prasad and Reddy 2015, Fernandez 2017, Johnson and Hayes 2016). Problem based learning approaches define a specific problem to be solved by the students, whereas project-based learning relies more on self-defined projects of the students. These methods target to motivate the students to be engaged with the material, show interest in the course contents, participate in the class and collaborate with other students. With regard to electrical engineering, PBL is commonly used, both for complete curricula like in (Macías-Guarasa et al. 2016) or for dedicated courses (Kumar et al. 2016). Many projects at university have a dedicated deadline and the time between start of the project and the deadline is often managed spontaneously by the student team. As most students have no experience in project management, sometimes just a few team members do all the work without any overall structure. Therefore, a dedicated project development method should be implemented.

Agile development focuses on flexibility, collaboration and self-organisation to increase the efficiency of a team during an iterative development process (Dyba and Dingsoyr 2009). The success of this methods relies strongly on dedicated professional skills of all team members, including team work, expedient communication and feedback, engagement and reliability. Acceptance of this method including all the required skills and tools for collaboration is essential for all team members. Hence, incorporation of agile development as dedicated PBL into university courses directly enables the students to improve their professional, communication and social skills and to train modern development processes, which make the students feel more confident in working together and also discussing problems.

1.1 Module Vehicle Systems

The course Vehicle Systems is part of the curriculum of the bachelor program Electrical Engineering at UAS Aachen (FH Aachen 2023). It covers different kind of systems in modern vehicles, from powertrain systems to advanced driver assistance systems (ADAS) and autonomous driving. The course consists of lecture (2 lessons per week), exercise and lab with 1 lesson per week, respectively. Up to 50 students participate in this one-term-course of 14 weeks every year. The previous knowledge of the students is rather heterogeneous as some students already finished a vocational training in the area of vehicle mechatronics or similar.

The goals of the course are rather simple: every student should gain competencies in technical fields and applications of vehicle systems as well as professional skills needed for modern development methods like agile development.

A flipped classroom concept was introduced for the module in the last years. During the lab, the students used a vehicle dynamics simulation software, IPG carmaker, to develop an adaptive cruise control system for a car (ACC). So far, all steps were predefined in the lab manual, from the initial setup and start-up of the software to the different development steps to realize the final system. In addition, an agile development method, Scrum, was introduced to increase professional skills of the students. The following description focuses on this introduction of agile development into the lab.

1.2 Agile development

Agile development is an established process for the iterative software development (Zhong et al. 2011). Its key element is a feedback loop which offers a continuous improvement not only of the product, but as well of the collaboration of the development team and the clients. The Agile Manifest defines four guiding principles (Cohn 2010). Individual strength and weaknesses of team members should be concerned and used so that the whole team learns interdisciplinary. The final product can only be achieved by reacting on changes during the implementing process, like changes of features of the productor financial, timing or personnel changes. This is a contrast to the normal development approach which focusses on fixed processes and working instruments, comprehensive documentation, a contract and plan agreed with the customer.

Goals of agile development are a higher motivation, engagement and productivity, as well as continuous working, iterative learning, a project structure by defining responsibilities and at the end a faster way to the final product state.

A common agile project method framework is Scrum. Here, three main roles define the Scrum team, which are the Scrum Master, the Product Owner and the development team (Gloger 2016). A sprint is a processing time interval for implementing a version or part of the product, the product increment. The sprints are supposed to have mostly the same length to maintain a continuity in working and planning, so time scheduling becomes easier. The product backlog defines a red line of tasks and is dynamic, in contrast to a linear project. The new prioritisation for the next sprint is continuously adjusted during the current iteration. At the end of a sprint the highest prioritised tasks are set to the sprint backlog to get implemented. The Product Owner is responsible for this procedure. At this point the Scrum Master has to accomplish the Sprint Review, Retrospective and Sprint Planning to organise a new working iteration and especially turning the focus on reflecting the previous collaboration. During the iteration the Scrum Master also organises Daily Scrums. This helps the whole team to get an overview of the project state and the responsibilities. Furthermore, the Scrum Master should identify possible collaboration problems in the Scrum team and help the team solving them.

2 METHODOLOGY

2.1 Concept and implementation

In 2022, 33 students participated in the course lasting for 14 weeks. The lab using Scrum for the ADAS development is based on the previously used lab. The initial structure of the lab is not change from technical point of view, incl. the dedicated tasks that are covered by the lab manual to develop an ACC system. This structure is maintained to ensure that all students are able to complete the tasks and to gain the required technical skills. The development of an emergency brake assist system (EBA) is added to the lab without dedicated tasks to enable a free and flexible work for the students. For both parts of the lab, the predefined and the free part, Scrum was used.

Depending on the group size the time effort and effort per person can be estimated as seen in Fig. 1. The time effort is most efficient with 5-7 people. The productivity per person is also better in smaller groups, but it does not vary that much between 1-7 people (Cohn 2010). For this project, productivity was defined as degree of achievement of the required professional skills and technical knowledge and a positive development within the process. Effort is referred to the time spent on the project. Referring to this statistical observation, six to seven students formed a Scrum team.

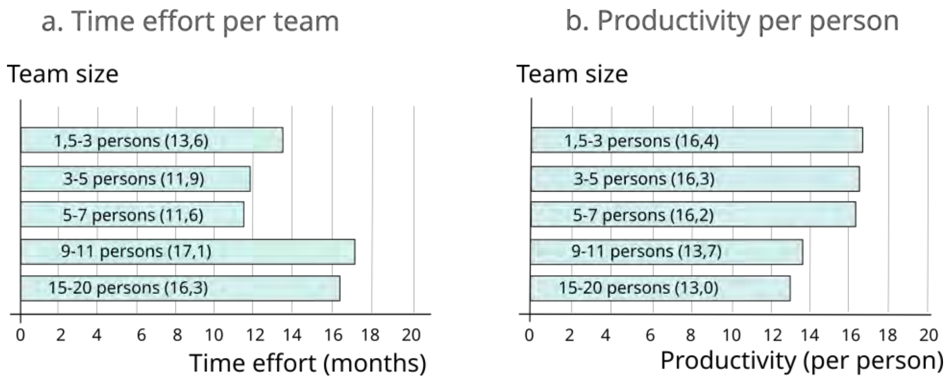

Fig. 1: Evaluation of team size acc. to (Cohn 2010)

The students self-selected their group at the beginning and hence, the groups differed in the composition of the team members. For some groups the team members already knew each other (group type 1), for other groups the team members did not know each other before (group type 2).

In general, the Scrum Master and the Product Owner should not be part of the development team to avoid personal conflicts (Cohn 2010). Nevertheless, all students should reach the technical goals of the course. Hence, for this project the Product Owner and the Scrum Master also act as team members to be able to follow the technical implementation completely.

Weekly Scrum meetings with supervision by a lecturer were held by each group. As it was impossible to implement a Daily Scrum event, every team accomplished at least one further meeting per week without supervision.

The supervision meetings started with the sprint review, where the product increment was presented, as well as the technical state of each team member. Afterwards the

Scrum Master moderated the retrospective. Positive feedback and observations of the last sprint, as well as problems were communicated, followed by discussions about improvements. The last step was the sprint planning to prioritize the next tasks of the product backlog, to estimate the effort and to assign the responsibilities.

The Product Owner communicated all technical requirements with the lecturers as needed. Another important task of the Product Owner was to update the Product Backlog and to ensure that the technical objective is achieved and that the quality requirements of the functions in IPG Carmaker were also observed.

To get an overview of the tasks and their current state as well as to update the tasks continuously, the online tool Trello was used (Trello 2023). The Trello boards were designed individually by the teams reflecting the four categories 'Stories/Product Backlog', 'Tasks/Sprint Backlog', 'Work in Progress' and 'Done'. To maintain the goal of technical learning success for all students, the 'Definition of Done' (Gloger 2016) in this project was that each team member implemented and understood the tasks.

At the beginning of the project a few moderation tips were given, but afterwards the students should first try to find their own way of moderating. During the supervised meetings recommendations were given when needed, e.g. how to handle a situation or how to structure a meeting. In the end, each group presented their organisational process and the technical results.

3 RESULTS

3.1 Evaluation

The evaluation of the implemented Scrum method is done in different steps, analysis of different aspects over project lifetime, observations of the lecturers, statements from the students and the official evaluation of the module.

Analysis of different aspects

Three different aspects – Scrum elements, group behaviour and results – with corresponding sub-items are analysed as depicted in Table 1. The analysis of the group behaviour was based on three sub-items reflecting the acceptance of the process by the Scrum Master and the group and the observation of active participation during the meetings. For the results, the communication within the group, the achievements during the project work and the retrospective were analysed. The numbers 'x/y' indicate the result of the analysis for each group at the beginning and the end of the project, respectively. As indicated by light green and green, the results improve significantly over project lifetime for most of the items and groups. In the end, all items but 3 achieve a very good result of 7 and more. Just for two groups the tool (Trello) is judged worse at the end of the project.

Observations by lecturers

As the two lecturers acted as supervisors during the weekly Scrum meetings, they are able to observe the group behaviour, the different roles and the communication very closely. Some observations show a clear difference between the two different group types, some observations were very much the same for both group types.

For all groups the direct communication improved during the project, in particular for groups of type 2. The initial meetings of these groups were rather silent, but after some time an active communication took place, strongly motivated by the corresponding Scrum Masters. Some groups established additional communication via a messenger for asynchronous communication between the meetings. This kind of communication did not work well, as questions were often answered too late from other team members, blocking the questioner with this task. The issue was solved in the Retrospective by forming sub-groups of two people. Other groups solved a similar problem with an additional online or presence meeting with the whole group.

Table 1. Analysis of different aspects of the implemented Scrum method on a scale from 0 (worst) to 10 (best). Numbers indicate the value at the beginning and at the end of the project. Yellow: slight deterioration, light green: slight improvement, green: strong improvement

	Scrum elements			Group behaviour			Results		
Group	Tool (Trello)	Roles	Procedure	Acceptance by group	Acceptance by Scrum Master	Active participation in meetings	Communication	Achievements	Retrospective
1	8/7	7/9	6/10	8/10	8/9	8/10	8/10	10/10	6/9
2	3/7	3/9	3/9	8/10	10/10	4/8	6/8	5/8	4/7
3	7/6	8/8	6/9	7/8	7/8	6/8	9/9	9/10	6/7
4	6/10	6/8	7/8	5/7	6/7	6/7	5/6	9/10	4/6
5	6/9	4/9	5/10	6/9	8/10	5/9	3/7	4/7	6/9

Initially, all Scrum Masters had to find their role as a moderator and they had to learn that their task is not to find the perfect solution by themselves. Over time, all Scrum Masters managed to moderate their group and the meetings properly, the moderation style and extent strongly depended on the group type. For group type 2 the moderation efforts were significantly higher. It was remarkable that the Scrum Masters learned to change their role from team member to Scrum Master and back easily.

For all groups there was a steep learning curve regarding the Scrum process. In the beginning, the technical status update, the retrospective and the sprint planning were not properly separated but were mixed up altogether. With some support of the supervisor all groups found a better meeting structure reflecting the Scrum process with separated sections for the update, retrospective and sprint planning. Groups of type 1 did not follow the process too close but sometimes started side discussions during the meetings. These discussions were stopped after some time by the Scrum Master. In general, groups of type 2 oriented themselves more exact on the Scrum rules compared to groups of type 1 reflecting the need for a clear structure to support the communication of the type 2 participants. Overall, the atmosphere in the groups was very harmonic and result-oriented.

The role of the Product Owner did not have a high significance in this specific project due to the missing customer and missing change requests. Anyway, the Product Owners supported the Scrum Masters and communicated technical questions with the lecturing professor. For the dynamic aspects of the project, in particular during the sprint planning with corresponding task prioritization, Trello as a taskboard was of great benefit for all groups. Open and new task cards were replanned according to their new prioritization and relevance. Due to missing experience with the tasks and the corresponding effort, sometimes not all tasks could be completed as planned, and sometimes the tasks were finalized long before the end of the sprint. In the latter case, the group reflected that they should have distributed the previous tasks better over time and iterations. All in all, the dynamic structure allowed the students to manage their time individually and to react on problematic tasks.

Direct feedback of students

After the course finished, the students were asked for direct feedback in form of a question-leaded discussion in plenum with all students and additionally of a group-internal reflection. All in all, the project work was considered to be very good and helpful for their future work, in particular the structure and the Scrum roles. The Scrum method was appreciated in general, but for some students the effort for implementing and living Scrum was too high. These students preferred to have more time to work on the technical topics. Trello gave a good overview of the status of the project and each team member. Also, the individual goals defined in each sprint were helpful to work continuously. All groups profited from the organizational skills and the efforts of the Scrum Master. Hence, as the Scrum Master acted also as developer, the effort for the Scrum Master was higher than for other team members. During the time the effort for the Scrum Master decreased as the meeting procedure was more clear. The role of the Product Owner was unclear in this context and the students proposed to include the role of a customer. Face-to-face meetings were preferred to online meetings and were usually more productive. Regarding the technical tasks, the students concluded that Scrum was more helpful for the free EBA task, including higher creativity, better teamwork and communication and increased use of Trello.

Module evaluation

The module was also evaluated with a standard questionnaire that is used for all modules, just about half of the participating students participated in the questionnaire. Some students judged the method to be ineffective and too time-consuming, especially for the first, conducted part of ACC development. However, it was considered more helpful for the EBA task. Others found it interesting and helpful for structure and teamwork.

3.2 Discussion

The purpose for implementing an agile development process was to increase the professional skills of the students and to introduce Scrum as a state-of-the-art tool. Professional skills like communication, role behaviour and process understanding were strengthened for all participants due to the interactive meetings and the agile project structure. Just little effort was spent by the supervisors in the beginning to introduce the process, to guide the initial meetings and to give some hints for improvement. The extra effort for the students was judged to be not too high, even though not all students liked this way of project work in the lab. In contrast, most students appreciated the learning outcome and agreed with the extra effort.

The effort for the Scrum Master, when also acting as developer, is higher compared to the other team members. On the other hand, Scrum Master benefits by increased management and organizational skills. Changing the Scrum Master during the project could spread this learning outcome also to other students, but at the expense of more unstructured project setup. This idea could be tested in following labs.

Due to missing customer or external change requests, the role of the Product Owner was not really useful in the current setup. In the next turn, either a customer request or change requests can be introduced by the lecturers to increase the work for the Product Owner.

The Scrum method fitted very well to the free part of the lab, the development of EBA. Here, all advantages and features of agile development were clearly visible for the students. Some groups worked in sub-groups with two students implementing different solutions for the tasks. During the following Sprint meeting advantages and disadvantages of the different solutions were discussed and the best fitting solution was selected, improving the project outcome.

For the conducted part of ACC development, Scrum did not fit that good due to missing dynamics of the project. But, based on this approach, Scrum was introduced rather softly, and the students could focus on the technical aspects first. Nevertheless, for future labs it could be tested to run the static part of the project (ACC) in a conventional way without Scrum, and to use Scrum just for the dynamic second part (EBA).

The final technical results of all groups were very good and very similar to former years. All groups managed to run the static part of the lab, and for the EBA development they found different, but always working solutions. Therefore, all technical learning goals were fully reached.

As Scrum is a general agile project management method, it can easily be transferred to other modules. According to the results of the implementation presented in this paper, the lab should contain at least some free parts. For these free parts Scrum could provide many benefits to increase the professional skills of the students, introduce and experience a modern development process maintaining the technical learning goals. The roles and the concrete implementation of the process can be adjusted to the modules easily as well.

4 SUMMARY AND ACKNOWLEDGMENTS

The introduction of Scrum as an agile development method into an existing lab of the module Vehicle Systems is presented. The purpose is to increase the learning outcome with regard to professional skills, maintaining the technical learning outcome. The lab consists of a conducted part and a free part, and Scrum is applied for both. The benefits of Scrum are higher for the free part of the lab reflecting the dynamic development of this part. In general, the effort to implement and lead the Scrum process is medium, whereas the extra efforts for the students is rather low. Nevertheless, the benefits for the students with regard to professional skills and process understanding is significant.

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CHALLENGE-BASED LEARNING IN COURSES: THE IMPLEMENTATION CONTINUUM

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ABSTRACT

Given the increasing criticality and complexity of societal challenges, higher education institutions are urged to equip students with the ability to develop sustainable solutions for 'wicked' problems. Consequently, the Challenge-based Learning (CBL) framework has attracted considerable interest in higher engineering education. However, transforming existing course curricula to CBL is a challenging endeavour since it requires careful and paced execution for maintaining the quality, synergy, and flow of existing education. Therefore, this paper proposes a perspective on CBL implementation that exemplifies a gradual transition towards educational CBL innovation while reflecting on the alignment, consistency, and coherence educators aspire to when designing courses. Accordingly, we introduce a CBL implementation continuum as a conceptual model, which connects CBL elements to Van den Akker’s Spider Web for curriculum design and describes a continuum of Mild, Moderate, and

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Intense CBL levels per Spider Web component. Moreover, the paper describes an online CBL implementation tool, which helps educators thoughtfully evaluate the current level of CBL in their courses and provides practical recommendations for a transition towards higher levels of CBL intensity.

1 INTRODUCTION

In this ever-changing world, humanity is confronted with inherently intricate, critical, and ever-evolving problems. Consider, for example, the issues of climate change, energy transition, pandemics, and social injustice. These so-called “wicked” problems require innovative approaches and competencies that transcend current methods of problem-solving. Consequently, higher education institutions are urged to equip students with the ability to develop sustainable solutions for wicked problems, in addition to teaching academic knowledge and soft skills.

As a result, Challenge-based Learning (CBL) has attracted substantial interest in higher education. In CBL, students, as well as teachers, field experts, and community members collaborate to actively address wicked problems relevant to their environment while acquiring deep content knowledge and advanced soft skills (Apple Inc. 2011; Nichols et al. 2016; Rodríguez-Chueca et al. 2019).

Key CBL elements are widely described in practical handbooks and scientific literature. This literature often outlines flexible learning paths, inter-/trans-disciplinarity, real-world impact, 21st-century skills, self-directed and inquiry-based learning, flexible teacher roles, stakeholder involvement, and flexible assessment as elements of CBL (Apple Inc. 2011; Nichols et al. 2016; Gallagher and Savage 2020).

Designing education, especially while embracing these CBL elements, is a wicked problem in itself. Practice shows that the transition to CBL can be difficult and requires careful execution since the rushed application of CBL in a course (re-)design can disrupt the balance of (ongoing) education.

To support teachers and educational designers in moving from established practices in higher education to the creation of fully realised CBL courses, we propose a conceptual model, the CBL Implementation Continuum, that exemplifies a gradual transition towards educational CBL innovation while reflecting on the alignment, consistency, and coherence that educators aspire to when designing courses. To create this model, first, we connected CBL elements to Van den Akker’s Curricular Spider Web components (Van den Akker 2003), reflecting the alignment, consistency, and coherence desired in a curriculum. Then, we developed a continuum of varying CBL intensity, defining Mild, Moderate, and Intense CBL levels per component of the Spider Web. In addition, we introduce an online tool that supports the implementation of CBL in course design based on the Implementation Continuum.

2 CONNECTING CBL ELEMENTS TO THE SPIDER WEB COMPONENTS

To connect CBL elements to Van den Akker's Spider Web, we started by summarising key CBL characteristics found in the relevant literature and identifying how these align with each Spider Web component. Next, to grasp how CBL implementation can vary in course designs, we examined the implementation of CBL at the University of Twente through three cases: a bachelor-level minor (C1), a master-level extracurricular module (C2), and a master-level curricular course (C3).

As a result, we propose a Mild-Moderate-Intense Continuum per Spider Web component. At the Mild level, we guide incorporating CBL essentials into existing educational structures. The Moderate CBL level builds on this, introducing more CBL elements into the curriculum and adding depth to the CBL experience. At the Intense level, we describe a full-scale implementation of CBL, where all elements are fully integrated into the course design.

The formation of the continuum definitions of the components of *learning rationale*, *grouping*, and *assessment* are illustrated as an exemplar within this article, reflecting the underlying reasoning behind the model.

2.1 CBL Learning Rationale

In Van den Akker's Spider Web framework, the *learning rationale* describes why students learn in a curriculum. In CBL, students learn to interact and have an impact on the real world (Apple Inc. 2011; Nichols et al. 2016). They are presented with a big idea, a wicked societal problem, which needs to be broad enough for students to define and choose actionable challenges that require a solution design (Apple Inc. 2011; Nichols et al. 2016).

To incorporate CBL into their course, teachers can start by introducing a big idea that encompasses a wicked societal problem. The big idea should empower students to define their own actionable challenges and design solutions while engaging with real-world communities and stakeholders. In the meantime, real-world impact within a curriculum can manifest in various ways. In Mild CBL courses, student impact is limited to providing recommendations for a challenge solution, while the implementation and evaluation of the solutions are left to others. In such a way, Mild CBL courses allow students to have a passive impact on the real world.

To elevate the implementation of CBL to a Moderate level, teachers can guide students in prototyping solutions and fostering a more active impact on the real world. Additionally, the literature emphasises the value of guiding students to personally connect with the big idea, as it increases the perceived sense of meaning (Apple Inc. 2011; Nichols et al. 2016). Thus, in Moderate CBL courses, teachers scaffold students in defining challenges that have personal relevance to them.

Lastly, a full-scale CBL experience empowers students to leverage their learning process for societal contribution and witness their influence on real-world communities. As a result, students are required to design and implement solutions that have an immediate impact on the chosen challenge and evaluate the effects of their solutions in real life (Apple Inc. 2011; Nichols et al. 2016).

In summary, the Mild CBL level, within the learning rationale, is characterised by interaction with the real world, passive impact, broad big ideas, wicked problems, actionable challenges of personal choice, and solution designs. The Moderate CBL level introduces the characteristics of active impact on the real world and challenges of profound personal relevance. Lastly, Intense CBL courses, in addition to the Mild and Moderate level descriptions, provide students with opportunities to have an immediate impact on the real world. See Figure 1 for a visual overview.

Applying these CBL levels to the learning rationale of the aforementioned cases, C2 and C3 were categorised as Mild CBL, while C1 was Moderate CBL. In both C2 and C3, students chose actionable challenges from a broad big idea presented by field stakeholders, but the big idea was confined to a specific case, limiting personal exploration. The solution design resulted in an advice report, creating a passive impact. Conversely, C1 offered a pool of big ideas for students to select from, facilitating the choice of a personally relevant challenge. C1 also enabled students to design prototype solutions and evaluate their effectiveness with primary stakeholders, creating a more active impact. If teachers of C1 would want to promote their CBL implementation to the Intense CBL level, they would scaffold the students in applying their solution designs in real-world settings and evaluate their effectiveness with a broader range of stakeholders.

2.2 CBL Grouping

The Spider Web's *grouping* component depicts with whom students are learning. When applied to CBL, literature accentuates the significance of fostering inter- or trans-disciplinary collaboration within a group for a deeper understanding of the big idea (Observatory of Educational Innovation 2015; Nichols et al. 2016; Gallagher and Savage 2020; Dieck-Assad et al. 2021). Consequently, Mild CBL level courses can start by enabling students of the same discipline to work together while looking at the challenge from diverse perspectives to ensure a rich and critical exchange of ideas.

To take CBL a step further, teachers can facilitate forming groups of students from various disciplines to foster a multidisciplinary perspective on the challenge (Nichols et al. 2016; Gallagher and Savage 2020; Dieck-Assad et al. 2021).

Finally, Intense CBL groups consist of students, *and* coaches (i.e., teachers), *and* stakeholders. In such a way, coaches and stakeholders enrich their team's understanding of the big idea and the real-world context while students provide original perspectives on the addressed topics. Ultimately, the group members become active co-learners, co-researchers, and co-designers (Baloian et al. 2006; Nichols et al. 2016; Chanin et al. 2018).

Accordingly, regarding the grouping component, Mild CBL courses enable students within the same discipline to collaborate and explore the chosen challenge from diverse perspectives. Moderate CBL courses encourage the formation of groups with students from various disciplines to foster a multidisciplinary perspective. The Intense CBL level requires forming groups of students, coaches, and stakeholders who actively collaborate as co-learners, co-researchers, and co-designers.

The three analysed cases were characterised by different levels of CBL on the grouping component. C3 had a Mild level of CBL, with students from the same discipline encouraged to collaborate interdisciplinarily. The students were expected to explore their challenges from diverse perspectives and leverage their personal experiences during the investigation. C2 was considered to have a Moderate-to-Intense level of CBL, as students formed multidisciplinary groups and were required to collaborate transdisciplinary, with occasional participation from primary stakeholders and teachers during team reflections. C1 had an Intense level of CBL, with multidisciplinary groups and active participation from the team coach and primary stakeholders throughout the process.

2.3 CBL Assessment

In CBL, assessment focuses on the learning process rather than the final product (Nichols et al. 2016). Mild CBL level courses can start by assessing both the learning process and the challenge solution. The assessment of the learning process can be restricted to an overall reflection on the progress made throughout the CBL experience. As for the learning product, CBL assessment usually draws attention to the feasibility of the solution design (Apple Inc. 2011; Nichols et al. 2016; Yang et al. 2018; Gallagher and Savage, 2020). Hence, similarly to the common assessment of projects, teachers and/or stakeholders of Mild CBL courses define assessment criteria focusing on utilising course content into solution designs and their feasibility.

Moderate CBL courses build on this by emphasising creativity and innovativeness of the solution design within the assessment criteria (Yang et al. 2018; Gallagher and Savage, 2020). Moreover, Moderate CBL courses incorporate critical reflections on the successes and failures of the learning process, as these are valuable for a CBL experience (Apple Inc. 2011; Nichols et al. 2016; Yang et al. 2018). Lastly, the literature introduces the role of a student as a co-assessor of the learning process (Nichols et al. 2016; Cruger 2017). Therefore, Moderate CBL courses allow student contribution to the assessment. Practically, it often manifests in students critically evaluating their progress.

Intense CBL courses take the evaluation of the learning process to the next level. Students and teachers become co-assessors of the learning process, choosing the assessment procedures and criteria (Nichols et al. 2016; Cruger 2017). They define the assessment criteria, which usually includes the assessment of students' achievement of personal learning objectives, decision-making, reflection on the successes and failures of the learning process as well as reflection on the solution design's creativity, innovation, and feasibility (Nichols et al. 2016; Yang et al. 2018).

Thus, Mild CBL courses assess both the learning process and the challenge solution, focusing on the effective utilisation of course content and solution feasibility. Moderate CBL courses incorporate creativity, innovation, and critical reflections on the learning process, allowing student contribution to the assessment. Intense CBL courses involve students and teachers as co-assessors, defining assessment criteria that encompass personal learning objectives, decision-making, reflection on the learning process, and evaluation of the solution design's creativity, innovation, and feasibility.

Accordingly, C2 was aligned with the Mild CBL level descriptors. C2 teachers evaluated both the learning product and the process, focusing on how students applied their knowledge and skills to their solution designs, the feasibility of the solution, and their overall reflection on the learning experience. C3 had a Mild-to-Moderate level of CBL, guiding students to reflect on process successes and failures as part of the assessment. C1 had Moderate CBL level elements, assessing the creativity and innovativeness of students' solution designs and prioritising reflections on the learning process. Assessment criteria in C1 focused on students' ability to justify their choices, evaluate their progress, and critically reflect on process successes and failures. Bringing the curricular design to the Intense CBL level in C1 would involve students defining the assessment procedures and criteria alongside teachers and stakeholders.

2.4 CBL Implementation Continuum

Accordingly, Figure 1 presents the CBL Implementation Continuum in full:

Learning Rationale: why are students learning?

Mild CBL:

- Interaction with the real world
- Passive impact on the real world
- Broad big ideas
- Wicked problems
- Actionable challenges
- Challenges of personal choice
- Solution design

Moderate CBL:

- Interaction with the real world
- ***Active impact*** on the real world
- Broad big ideas
- Wicked problems
- Actionable challenges
- Challenges of personal choice
- Challenges of ***profound personal relevance***
- Solution design

Intense CBL:

- Interaction with the real world
- Active ***and immediate impact*** on the real world
- Broad big ideas
- Wicked problems
- Actionable challenges
- Challenges of personal choice
- Challenges of profound personal relevance
- Solution design

Learning Objectives (LOs): towards which goals are the students learning?

Mild CBL:

- Reflection on existing knowledge and skills is facilitated
- Students mainly work towards pre-defined specific learning objectives

Moderate CBL:

- Reflection on existing knowledge and skills is facilitated
- A pool of ***pre-defined broad LOs*** (incl. academic and 21st-century skills) is presented
- Students are independent in ***choosing LOs from the pool***

Intense CBL:

- Reflection on existing knowledge and skills is facilitated
- Students are ***independent in defining personal LOs***
- Academic knowledge and 21st-century skills are ***encouraged***

Content Knowledge (CK): what are the students learning?

Mild CBL:

- Groups of students together gain inter-/trans-disciplinary knowledge (content and soft skills)
- The scope of CK is mainly defined by the course
- The scope of CK is partially defined by students' challenge investigation needs

Moderate CBL:

- Groups of students together gain inter-/trans-disciplinary knowledge (content and soft skills)
- The scope of CK is ***partially*** defined by the course
- The scope of CK is ***partially*** defined by students' challenge investigation needs

Intense CBL:

- Students ***independently gather disciplinary knowledge*** (content and soft skills)
- A group of students ***combine*** their disciplinary knowledge and ***build*** an inter-/trans-disciplinary ***knowledge base***
- The scope of CK is ***entirely*** defined by students' challenge investigation needs

Learning Activities: how are the students learning?

Mild CBL:

- Interaction with the real world
- Passive impact on the real world
- Broad big ideas
- Wicked problems
- Actionable challenges
- Challenges of personal choice
- Solution design

Moderate CBL:

- Students (individuals or groups) engage with a wicked problem (i.e., big idea)
- They identify an actionable challenge
- They deeply investigate the challenge
- They ***independently engage with the primary stakeholder***
- They design a consciously chosen solution
- They (indirectly/directly) implement the solution in the real world
- They ***evaluate the effects*** of the solution
- A ***cycle*** of ***reflecting*** and ***documenting*** follows the process

Intense CBL:

- ***Individual students engage*** with a wicked problem (i.e., big idea)
- ***Individual students identify immediate*** actionable challenges
- Students ***form groups*** based on their actionable challenge
- The group deeply investigates the challenge
- The group engages with ***any relevant stakeholder*** independently
- The group designs a consciously chosen solution
- The group ***directly*** implements the solution in the real world
- The group evaluates the effects of the solution
- A cycle of ***reflecting, documenting, and sharing*** with the public follows the process

Teacher Role: how is the teacher facilitating the students' learning?

Mild CBL:	Moderate CBL:	Intense CBL:
• A learning supervisor (expectation manager, process facilitator) • Field experts and professional advisers	• A learning supervisor (expectation manager, process facilitator) • A ***coach*** (a ***learning guide***) • Field experts and professional advisers	• A learning supervisor (expectation manager, process facilitator) • A coach (a learning guide, ***co-researcher/co-designer/co-learner***) • Field experts and professional advisers

Materials & Resources: with what are the students learning?

Mild CBL:	Moderate CBL:	Intense CBL:
• Teachers prepare guiding resources • Students must familiarise themselves with the guiding resources • Students are encouraged to explore additional resources • Technology can be used	• Teachers prepare guiding resources • Students ***can choose to*** familiarise themselves with the guiding resources • Students are encouraged to explore additional resources • ***Open access to technology is provided***	• Teachers prepare guiding resources • Students can choose to familiarise themselves with the guiding resources • Students are encouraged to explore additional resources • Open access to ***state-of-the-art technology*** *is provided*

Grouping: with whom are the students learning?

Mild CBL:	Moderate CBL:	Intense CBL:
• Students form a group of co-learners • Inter-/trans-disciplinary collaboration is fostered	• Students form a ***multidisciplinary group*** of co-learners • Inter-/trans-disciplinary collaboration is fostered	• A multidisciplinary group of ***co-learners*** consists of: – ***students*** from different disciplines – ***coaches*** (teachers) – ***stakeholders*** • Inter-/trans-disciplinary collaboration is fostered

Location & Time: where and when are the students learning?

Mild CBL:	Moderate CBL:	Intense CBL:
• Fixed learning in the real world • Fixed L&T for the offered learning activities • Flexible L&T for self-regulated learning and group work • A collaborative virtual and/or physical workspace is accessible by schedule	• ***Semi-fixed*** learning in the real world • ***Semi-fixed*** L&T for the offered ***learning activities*** • Flexible L&T for self-regulated learning and group work • A collaborative virtual and/or physical workspace is accessible by schedule	• ***Flexible*** learning in the real world • ***Flexible*** L&T for the offered ***learning activities*** • Flexible L&T for self-regulated learning and group work • A collaborative virtual and/or physical workspace is ***constantly accessible***

Assessment: how is the students' learning assessed?

Mild CBL:	Moderate CBL:	Intense CBL:
• The learning product and process are assessed • Teacher- and/or stakeholder-defined criteria include: – the incorporation of the acquired content and skills into a solution design – the feasibility of the solution • Critical reflection on the process/progress is assessed • Teachers and/or stakeholders conduct the assessment	• The learning product and process are assessed • Teacher- and/or stakeholder-defined criteria include: – the incorporation of the acquired content and skills into a solution design – ***creativity*** and ***innovativeness*** of the design – the feasibility of the solution • Critical reflection on ***process successes and failures*** is assessed • Students ***can contribute*** to the assessment • Teachers and/or stakeholders conduct the assessment	• The learning process is assessed • The ***student and teacher-defined criteria*** include: – students' ***personal progress*** – students' ***decision making*** – **the reflection** on the creativity and innovativeness of the design – **the reflection** on the feasibility of the solution • Critical reflection on process successes and failures is assessed • ***Students and teachers choose the assessment procedure*** • Students and teachers ***co-assess the process***

Fig. 1. The CBL Implementation Continuum

3 FACILITATING CBL IMPLEMENTATION WITH AN ONLINE TOOL

An online interactive tool has been developed to guide teachers in using the CBL Implementation Continuum when (re-)designing courses. The tool combines the continuum with an evidence-based database of practical advice on how to transition to higher levels of CBL intensity. The advice database was collected from CBL practices and experiences at the University of Twente and knowledge on CBL implementation available in the literature. The tool first asks users to indicate the current CBL level of their course and the desired one for each curricular component. Based on the users’ input, the tool visually presents the gap between current and desired levels of CBL in the form of a spider web. Then, based on the presented gap, the tool compiles an advice report on how the users can bridge the gap between the current and the desired levels of CBL intensity. The tool is also designed to gather user feedback for regularly updating and continuously improving the offered advice and the level descriptors.

4 CONCLUSIONS AND FURTHER WORK

The CBL Implementation Continuum offers a practical approach for integrating CBL into higher education and suggests that courses can gradually evolve towards CBL innovation. Such a perspective can foster an increase in CBL acceptance in higher education. It prompts teachers to capitalise on what they are already doing in their courses and add new CBL elements to their curriculum step by step.

Notably, we present the CBL Implementation Continuum as a heuristic prototype. Intense CBL level descriptors were derived from literature, which details elements common to CBL, while Moderate and Mild level descriptors were heuristically deduced from CBL practice at the University of Twente. Moreover, the presented model does not consider the CBL-compass of Van den Beemt et al. (2023), as their work was published after the continuums were defined. Thus, we endorse further developments of the model and the level descriptors as new knowledge on CBL emerges.

In addition, as Van den Akker (2006) noted, while the emphasis of curriculum design on specific Spider Web components may vary, alignment is crucial for maintaining coherence. Teachers using the CBL Implementation Continuum should be aware that strengthening the intensity of one component while neglecting another could jeopardise constructive alignment. As such, they should remain mindful of this risk and adjust their approach as needed.

The CBL Implementation Continuum invites new research endeavours, which can considerably contribute to the scientific understanding of the educational approach. For instance, the model and the tool can be used in research on CBL to operationalise and measure the levels of CBL implementation. Furthermore, investigations could explore the impact of varying levels of CBL intensity on students' learning and skill development. Additionally, empirical recommendations on the most appropriate intensity levels for a course could be explored based on factors such as classroom size, course boundary conditions, and long-term curricula goals.

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FIRST STEPS TOWARDS GAMIFICATION OF ONLINE PHYSICS AND MATHEMATICS ASSIGNMENTS

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Conference Key Areas: *Fundamentals of Engineering: Mathematics and the Sciences, Innovative Teaching and Learning Methods*
Keywords: *gamification, engagement, engineering mathematics, engineering physics*

ABSTRACT

The objective of this practice paper is to describe and analyse the use of online learning tasks on engineering mathematics and physics courses. The development of learning tasks was inspired by the promising effects of gamification techniques in higher education. Hence, some gamification elements, such as bonus points and immediate feedback were integrated into the learning tasks. Course results and student feedback demonstrate the positive impact of gamification of online learning tasks on students' motivation and learning. In the end, further possibilities of increasing the number and repertoire of gamification techniques in engineering mathematics and physics courses are discussed.

1 INTRODUCTION

Many universities are currently developing domestic and international distance learning programs and other means to provide distant and continuous learning experiences in engineering. These often result in growing student intake as well as increasing diversity in the starting level knowledge and skills of the students. This situation, in turn, calls for the development of motivating and pedagogically meaningful online tasks with diverse and continuous automatic evaluation.

Well designed and constructed online tasks can simultaneously increase students' understanding of the topic and their motivation. One advocated approach for creating these is the gamification of education and game-like elements, such as scores, rewards, and challenges, have been shown to have the potential to promote learners' motivation, engagement, and performance (Alomari, Al-Samarraie and Yousef 2019). Points, leaderboards, badges, and levels are the most often used gamification techniques in university education (Alomari, Al-Samarraie and Yousef 2019) as well as in engineering education (Milosz, and Milosz 2020). Points and badges refer to rewards assigned for completing a task, leaderboards to display the ranking of the players, and levels to the variance of difficulty of player's actions (Milosz, and Milosz 2020).

The fifth most common gamification technique used in engineering education is feedback, which helps the players to avoid getting confused or lost (Milosz, and Milosz 2020). In learning situations, the feedback from game-like tasks can offer a constructive way to communicate that there was a mistake in the student's work, but also to praise them for a task well performed (Yong et al. 2021). Research shows that feedback is an integral part of learning and a pre-requisite in constructing new information structures (Yong et al. 2021), (Krause, Stark and Mandl 2009). Learning is more efficient the more often personalised feedback is received. In game-like tasks, errors and mistakes can be corrected based on instant feedback and hints. Mistakes should not be overly avoided but they should be seen as a way to improve one's learning (Yong et al. 2021).

Solving mathematical problems provides good grounds for gamification. Correct answers can be rewarded with points or badges, the requirement level can be adjusted through the complexity of the problems, most typical mistakes can be pointed out through hints and feedback, and the collected points can be used as the basis for leaderboards or progress bars. In addition to learning mathematics, gamification elements can also foster students' learning skills when they plan for the best gaming tactics, and even their interaction skills when they consult their peers for better success (Ariffin et al. 2022).

Online learning tasks with gamification elements encourages and motivate students to participate more actively in the learning process. The active role of the learner improves learning results. The active role of learner is included in the constructive learning theory (Hui, and Mahmud 2023). According to the constructivist learning theory, the learning process is self-directed and that creates new understanding and knowledge for the learner (Agarkar 2019).

In our work in university-level engineering education, we added game-like elements to online learning tasks in physics and mathematics. Here, we present our experiences on the effects of interactive online tasks on student learning and motivation from one such course, 'Basics of Vibration and Wave Motion'.

2 METHODOLOGY

2.1 Description of course implementation

The bachelor program first-year physics course (Basics of Vibration and Wave Motion) utilizes weekly independent online assignments. This course is worth two ECTS credits and it extends over seven weeks. The course includes lectures, assignments, independent weekly online exercises, and an examination at the end of the course.

2.2 Evaluation of the course

At the beginning of the course, the students are presented with the evaluation criteria. The course grade is determined by the examination at the end of the course. The final online examination includes 5 tasks with 10 points each, resulting in 50 points as the total maximum.

Additionally, it is possible for the students to raise their accepted grades by one by independently completing weekly online tasks. These voluntary tasks provide a maximum of 6 extra points (EP), based on equation (1), where r indicates the percentage of correctly solved weekly extra tasks.

$$EP = \frac{r}{100\,\%} \cdot 6 \tag{1}$$

For example, if the student achieves 35 points from the exam and has completed 69% of additional tasks ($EP = 4.14$), the student receives a total of 39.14 points. The final grade is assigned according to Table 1.

Table 1. Determination of grade from points

Grade	Points
0	< 23
1	23 - 28
2	29 - 34
3	34 - 40
4	41 – 45
5	46 – 50

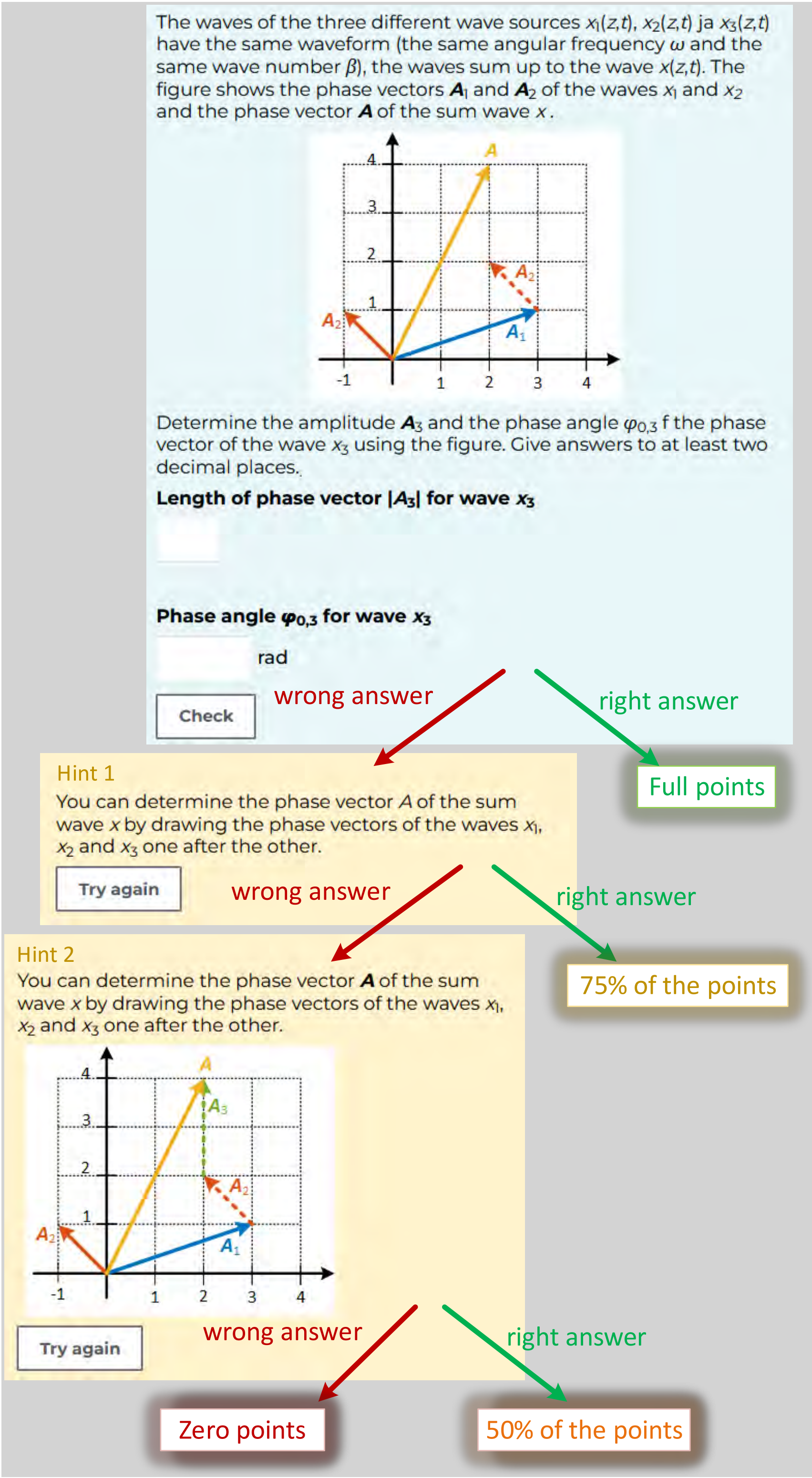

Fig. 1. Example on a numerical question and the scoring principle.

2.3 Online learning tasks

The weekly online exercises of the study unit are diversely implemented. By completing them, students' learning from the weekly subject is measured and deepened. The exercises are evaluated automatically and gamification elements like instant feedback as well as interactive hints are utilized. The exercises involve multiple choice questions, image interpretation and calculation tasks.The student gets instant feedback about if the answer was right or wrong. If the answer was right the student gets full points. If that is not the case the student gets a hint. The new trial gives 80% of the maximum points as a result of success. The student can have 2 or 3 new trials depending on the question. In figure 1, an example on numerical question is shown.

3 RESULTS

3.1 Tables

Thetask completion rate, lecture attendance and participation in either contact or video tutorial session have been recorded weekly, with results shown in Figure 2.

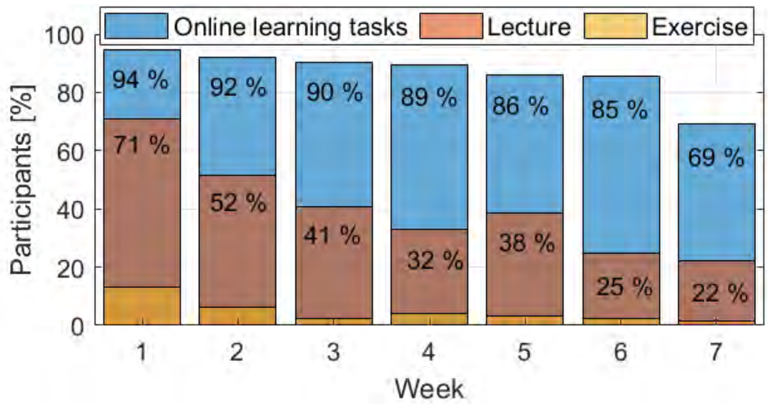

Fig. 2. Students‘ completion rate of online tasks and attendance on lectures and exercise/tutoring sessions in percentage.

The arithmetic mean of online task completion was 87% of students, lecture attendance 47% and exercise session attendance 15%. Comparatively, students were significantly more active in doing the online tasks. The conclusion is that despite these tasks being also in practice optional, students were motivated to complete them. To explore the benefit between completing online tasks and learning results, the arithmetic mean of the final grade for each quintile of online task completion has been observed in Figure 3.

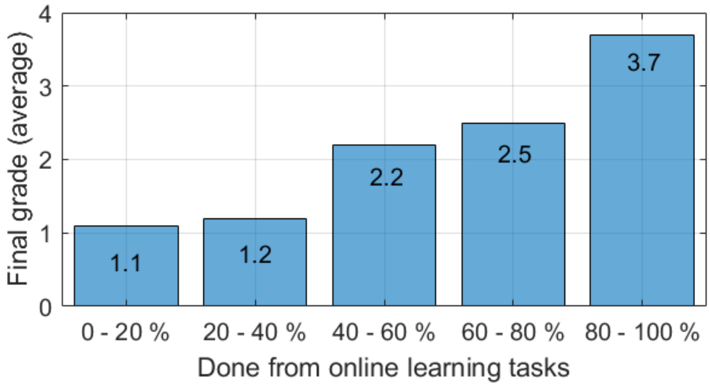

Fig. 3. Correspondence between online task completion percentage and final grade.

Students who have done more than 80% of online tasks had a final grade average of 3.7 (out of maximum 5.0) whereas students who had done less than 40% of online tasks had a final grade average of slightly more than one.

After completing the course, feedback was collected from the students, using the evaluation of several statements. Figure 4 shows the responses to the statement ”*Course’s online learning tasks supported my learning*”.

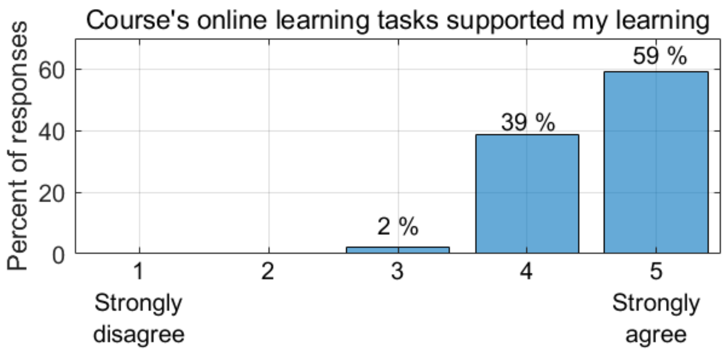

Fig. 4. Distribution of replies to ”Course’s online learning tasks supported my learning” in percentage.

The arithmetic mean of the replies was 4.6 and the standard deviation was 0.5. A total of 59% of replying students strongly agreed that the online tasks supported their learning.

In free verbal feedback, students made the following comments, among others:

> ”*The online learning tasks were nice and just suitably challenging*”
>
> ”*Challenging tasks and rewarding when solved*”
>
> “*Online learning tasks supported learning a lot, especially because tasks have multiple attempts with hints*”
>
> “*Weekly online learning tasks motivate continuous learning*”

4 LIMITATIONS OF THE METHODS AND STUDY

Gamification of learning often focuses on teaching concepts with measurable outcomes, well-defined rules, and quantification. To embed qualitative tasks that involve reflection, interpretation, and critical analysis might be challenging but not impossible. Another limitation is to provide personalised and meaningful feedback, particularly on qualitative tasks. Moreover, gamification heavily focuses on grasping student's attention by giving immediate rewards, feedbacks and competition. Complex skills, such as critical thinking, logical reasoning, and narrative building might not be achieved by the gamification of simple exercises.

Our study was also conducted within limited subjects and a single university; it might be better to use more diversified approaches in future studies. The study period of the analysed courses is seven weeks, but results could differ if the study period is longer.

5 SUMMARY AND ACKNOWLEDGMENTS

Course statistics show that the students were highly motivated to do the voluntary online learning tasks even though the effect of the tasks on the final grade was rather small. Completing online learning tasks was much more common than attending the lectures or exercises throughout the course and the temporal decline in the activity of doing the tasks was smaller than for other activities during the course.

The effect of online learning tasks for learning was evident, with a positive correlation between the task completion rate and final grade. Although active completion of the learning tasks was rewarded by increasing the final grade by a maximum of one category, this was not enough to explain the differences in grades between those having done a little and those having done a lot of learning tasks. Also, the student feedback indicated that the learning tasks strongly supported their learning.

Qualitative feedback from students revealed that the students perceived the online learning tasks to be suitably challenging, motivating and rewarding. The feedback in the form of hints was also appreciated. These, as well as the quantitative findings, are all well aligned with the discovered effects of different gamification techniques (Alomari, Al-Samarraie and Yousef 2019, Ariffin et al. 2022).

Based on this preliminary study, it is not yet possible to draw far-reaching conclusions about the effect of online tasks with gamification elements on learning. In the future potential feedback loops and further individualization of the course to the student level (e.g., adjusting difficulty level) should be considered. It would be also possible on the currently used learning management system to add other gamification elements, such as high score tables. These will be the next steps in the gamification of online learning tasks, which will be study in the future.

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NINE YEARS OF SYSTEMATIC CAD COURSE DEVELOPMENT: WHAT DID WE LEARN?

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Conference Key Areas: *Engineering Skills and Competences, Curriculum Development*
Keywords: *CAD, course development, feedback, mechanical engineering*

ABSTRACT

Computer-Aided Design (CAD) plays a vital role in the curriculums of mechanical engineering degree programs, empowering students to conceptualize and visualize their designs, thus enhancing their abilities as engineers. This abstract presents the implementation of a multi-CAD course conducted between 2014 and 2022, catering to hundreds of students from diverse disciplines, including mechanical and civil engineering. Throughout the course, student feedback was systematically collected to assess learning outcomes and measure the effectiveness of different learning tools and methods.

The course employed a range of tools, including automatically graded quizzes and a dedicated CAD model assessment system, which not only lightened the workload of teaching assistants in terms of assessment but also allowed them to focus on guiding and supporting students. Additionally, surveys conducted at the beginning and mid-term stages provided valuable insights into students' initial proficiency levels and their study patterns during the course.

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Significantly, the course successfully transitioned to fully online teaching during the period of remote instruction from 2020 to 2022. Lessons learned during this time were integrated into the regular practicalities of CAD course teaching, ensuring continued effectiveness and adaptability.

Improvements in student performance and feedback, observed during the implementation of the multi-CAD course, demonstrate the impact and success of the teaching methods employed.

1 INTRODUCTION

Computer-aided Design (CAD) has become a fundamental tool for mechanical engineers, resulting in the inclusion of CAD courses in university curricula worldwide. In certain countries, the prescribed amount of CAD instruction is even specified at the national level [1].

Traditionally, CAD education has focused on mastering software tools, and assessment has primarily relied on computer exercises or project work. Lectures are often provided alongside these courses to support students in completing the exercises and developing a comprehensive understanding of CAD model creation and its applications in areas such as simulations and manufacturing.

The primary objective of CAD education is to equip students with the necessary tools to support their future studies and professional endeavors. CAD courses are typically conducted during undergraduate studies, with the expectation that students pursuing master's level studies already possess these skills. The CAD modeling software commonly used is commercially available (such as Creo, Inventor, Solidworks, Solid Edge, NX), designed for professional use, which poses a challenge for students to learn. Although there have been attempts to develop CAD tools specifically for educational purposes[2], commercial tools remain prevalent due to their relevance in summer work, internships, and post-graduation employment.

Due to the critical nature of CAD knowledge for early-stage mechanical and civil engineers, the enrollment in basic CAD courses can be substantial, reaching as high as 400 students. This presents challenges in terms of available study spaces and the assessment process. Several studies have explored automating the grading process for 3D CAD models [3,4] aiming to expedite assessment and provide students with timely feedback on their learning progress.

This study outlines the structure of a CAD course, its evolution over the years, the feedback received, and how systematically collected student feedback has been utilized to enhance the course. To accommodate the large number of enrolled students, this course was progressively developed with a wide array of online tools, alleviating the burden of assessment for instructors and enabling a comprehensive overview of student progress. These tools and methods played a pivotal role in addressing the challenges posed by the COVID-19 restrictions from 2020 to 2022, facilitating a successful transition of the course to an online format. Subsequently, as restrictions eased, the course was gradually reintroduced in face-to-face teaching.

Additionally, this paper presents a new CAD course tailored specifically to mechanical engineering students, built upon the learning outcomes derived from the nine years of course development

2 STRUCTURE OF THE COURSE

The *Computer-aided Tools in Engineering* course is mandatory for three different majors offered by the School of Engineering: Mechanical and Civil Engineering, Energy and Environmental Engineering, and Built Environment. In addition to covering CAD tools for mechanical engineering, this course also introduces CAD tools specific to civil engineering and Geographic Information System (GIS) tools used in land surveying. The course attracts an average of approximately 350 students annually.

The course aims to achieve the following learning outcomes:

- Familiarize students with the basics of computer-aided tools, enabling them to implement these tools in their respective fields and evaluate their suitability for various subjects.
- Develop students' understanding of the characteristics and limitations of computer-aided modelling, as well as the practical methods of applying these tools in industrial and research contexts.

Spanning a duration of 14 weeks, equivalent to 5 ECTS credits, the course is divided into two seven-week periods. It incorporates weekly lectures covering different topics and weekly computer exercises conducted in computer labs. The course grading is based on a pass/fail system where 80% completion of each exercise is required. During the exercise sessions, students submit their completed computer exercises by demonstrating their models to teaching assistants, who then assess their work. Feedback from students is collected through an end-of-course survey, which gathers input on their overall satisfaction with the course grade, teaching organization, workload, and perceived benefits from the knowledge gained.

By adopting this structure and assessment approach, the course provides students with practical hands-on experience and allows them to apply their skills under the guidance of teaching assistants. Furthermore, the feedback survey serves as a valuable tool for continuous improvement and refinement of the course content and delivery

3 NINE YEARS OF COURSE DEVELOPMENT

This chapter highlights recent changes in the course syllabus, focusing on structural and tool-related modifications. The course has been part of the curriculum since 2014. *Table **1*** presents numerical data from the course feedback survey, starting from 2015. The feedback survey used a grading scale from 1 (fair) to 5 (excellent) for categories such as General Grade, Teaching Methods, and Usefulness. The Workload category had a scale of 1 (less work), 3 (expected amount), and 5 (too much work). The data from 2014 was excluded due to changes in the feedback survey form and scales, making it incomparable.

These changes aim to improve the course's learning experience and align with evolving educational practices. The feedback survey data provides insights into the effectiveness of these modifications, guiding further course development and refinement.

Table 1. Numerical data from yearly feedback surveys

Year	Number of respondents	General Grade	Teaching methods	Workload	Usefulness
2015	82	3,49	3,63	3,54	4,34
2016	69	3,87	3,96	3,42	4,66
2017	147	3,90	3,95	3,35	4,66
2018	107	3,94	4,08	3,52	4,64
2019	118	3,97	4,16	3,63	4,64
2020	120	3,83	3,81	3,54	4,59
2021	149	4,11	4,14	3,39	4,62
2022	122	3,49	3,89	3,39	4,50

3.1 Initial course (2014)

The initial course structure, depicted in *Fig. 1* , comprised a Common module and a choice of two modules from a selection of five. The Common module covered general topics such as data storage techniques and advanced computer model utilization, including learning diaries as part of the assessment.

Students selected one module in each period, participating in lectures and practical computer exercises held in computer labs. The modules introduced various software tools, including Autodesk AutoCAD (2D-CAD), Siemens Solid Edge (3D-CAD), PTC Creo (Mechanical Engineering CAD), Trimble Solutions Tekla (Civil Engineering CAD), and Esrin ArcGIS (Land Survey GIS).

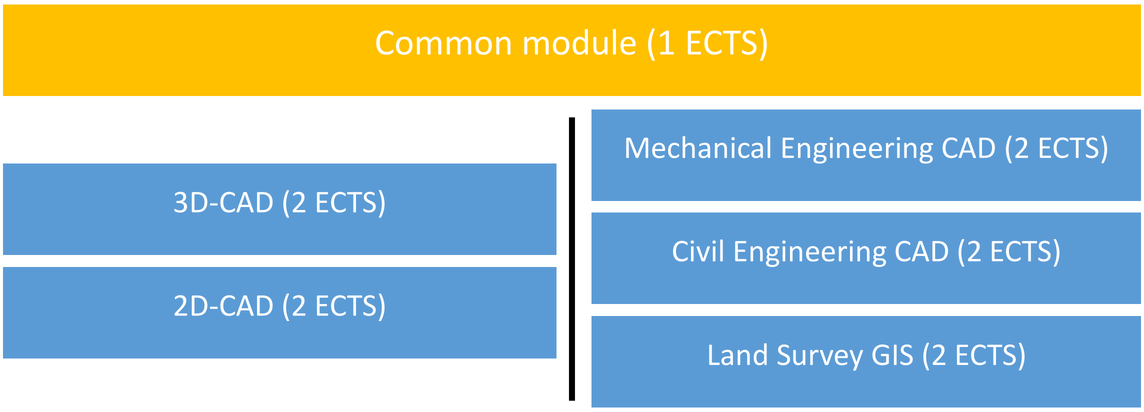

Fig. 1. Structure of the initial course

3.2 First iteration (2015)

In the first iteration of the course in 2015, the course structure was streamlined. The Common module was removed, and clearer module selections were introduced (*Fig. 2*). Now, students participated in two modules focusing on 2D and 3D CAD tools in the first period, followed by one selective module in the second period.

This change aimed to ensure that all students developed essential skills in both 2D and 3D CAD tools, which are crucial in fields like energy technology where layouts are in 2D and components are in 3D. As a result, the learning diaries were removed to allocate more time for practical training and hands-on experience with computer tools. This decision was strongly supported by student feedback.

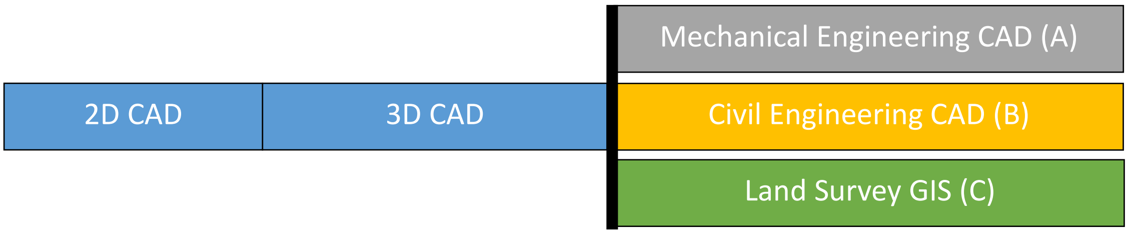

Fig. 2. Streamlined course structure

3.3 Quizzes (2017)

Creating engineering drawings according to standardized rules can pose a significant challenge for students. These drawings are intricate, requiring the memorization and recognition of numerous symbols, the creation of cross-sections and projection views, and the completion of header information fields. To support students in mastering these skills, an Engineering Drawings Symbols quiz was developed within the Moodle platform.

The quiz provided students with an opportunity to practice applying projection rules (as shown in *Fig. 3*) and recognizing various symbols used in engineering drawings. By engaging in interactive quizzes, students could enhance their understanding of these critical elements.

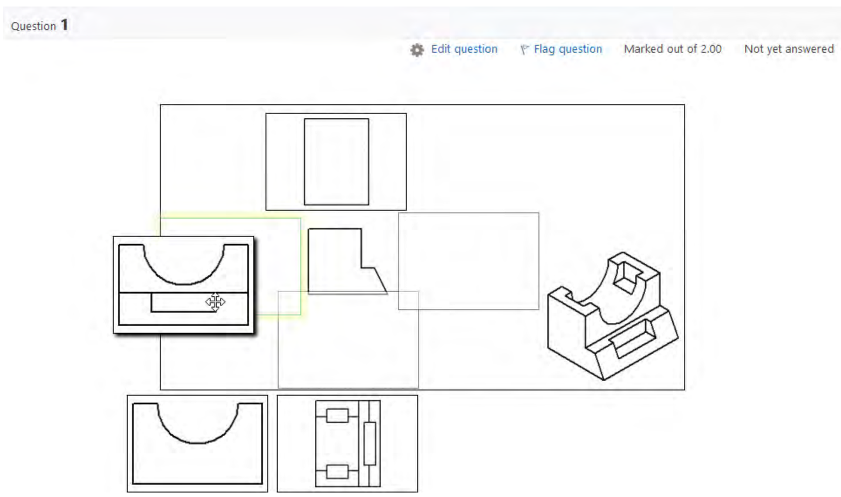

Fig. 3. An example question about projection rules, where a correct projection is needed to drag on its correct location

The quiz was automatically graded, and student had several attempts to get the required 80% right. The questions were randomized and selected from the pool of questions.

3.4 Additional Surveys (2017)

In 2017, two mandatory surveys were introduced: the starting survey and the mid-term survey. These surveys aimed to collect more comprehensive feedback throughout the course, enabling timely adjustments and enhancing the student experience.

The starting survey gathered information on students' backgrounds, computer usage experience, general computer skills, and attitudes towards learning CAD. This data provided valuable insights into their starting point, allowing for tailored course adjustments.

The mid-term survey assessed students' progress in learning CAD and their attitudes towards computer-aided tools. By collecting feedback during the course, instructors gained a better understanding of students' experiences, identifying areas that required additional support or clarification.

3.5 Automatic Assessment Systems (2018)

The assessment of CAD models is a time-consuming task, often with variations among teaching assistants and teachers in the assessment process and criteria. To ensure the accuracy of engineering drawings, it is crucial to verify the correctness of the CAD models before proceeding further.

To streamline the assessment process, two automatic assessment systems were implemented in the course. The first system compared the shape of the model with a reference model (*Fig. 4*), while the second system modified the CAD model's parameters and evaluated its response to changes [3].

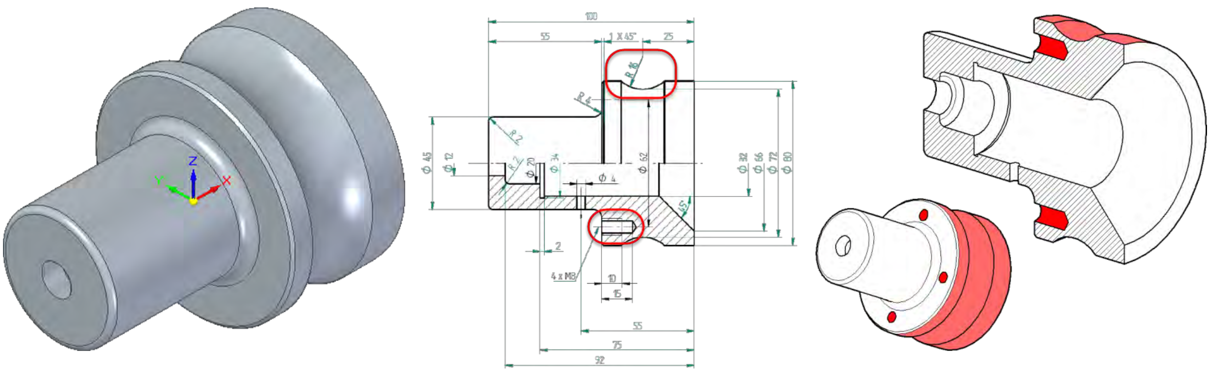

Fig. 4. From left to right: Student's returned model, comparison to reference model and mistakes made, feedback picture from the system highlighting errors in the shape [3]

By incorporating these automated assessment systems, the need for exercise demonstrations during computer sessions was reduced. This provided students with the convenience of submitting their CAD models independently, at their preferred time and location, which was well-received by the students.

3.6 Remote Teaching (2020-2022)

The year 2020 presented significant challenges for universities, with the sudden transition from in-person to remote teaching. Fortunately, the CAD course had existing online materials and tools in place for distributing and grading student work, making the transition surprisingly smooth. An online version of the course had also been developed beforehand [5].

The main challenges arose from installing necessary computer tools on students' personal computers. This was resolved by providing virtual computers with remote access, where all required tools were pre-installed. Exercise sessions were conducted via MS Teams, allowing students to share their screens and seek assistance from course staff.

The shift to remote teaching also impacted the submission of larger exercises. Previously, most modelling tasks were automatically assessed, with only a few more creative assignments demonstrated during computer exercises. However, in the remote setting, students were asked to create demonstration videos showcasing their models and their performance, as creative tasks without predetermined correct answers could not be assessed automatically.

4 CURRENT INPLEMENTATION

Following the renovation of the bachelor program, the previous common CAD course was replaced with two discipline-specific courses: mechanical engineering and civil engineering. The new mechanical engineering CAD course continues to utilize the tools discussed in the previous chapter. With this change, the number of students decreased from over 400 to approximately 250. Since it is now a single-discipline course, only one mechanical engineering CAD software, PTC Creo, is utilized.

This shift in discipline provided an opportunity to enhance the mechanical CAD teaching by incorporating more advanced modelling techniques, including skeleton and surface modelling. Consequently, the grading system was modified from pass/fail to a scale of 0-5 (0 representing fail and 5 representing excellence). This change was requested in the feedback received, as it allows for better recognition of students who invest time and effort in learning the tools and methods, rather than simply aiming to pass the course with minimal effort.

5 DISCUSSION

The CAD course received positive feedback from students since its inception. While there were concerns about the course's relevance to land survey and real estate economics students, the increasing demand for 3D models and evolving industry trends justified the inclusion of CAD skills in their education.

The introduction of quizzes and additional surveys in 2017 had a minor impact on feedback grades. The engineering drawings quiz aided students in completing their tasks, resulting in a slight reduction in perceived workload.

The implementation of automatic assessment in 2018 improved classroom guidance by allowing teaching assistants more time to assist students during computer exercises. However, it increased the workload for responsible teachers as the system identified more modeling mistakes, necessitating additional effort to address and rectify them. Clearer guidelines for automatically assessed models can help mitigate this issue.

The experience of remote teaching in 2020-2022 yielded varying feedback grades. The initial drop in 2020 can be attributed to the sudden transition, while the subsequent increase in 2021 reflects familiarity with remote teaching methods. The decline in feedback grades in 2022 may be attributed to the hybrid nature of teaching, causing confusion among students.

Future development of the course includes creating self-assessment quizzes on key tools and methods and providing in-depth knowledge on advanced CAD modeling techniques.

The learnings from the CAD course development include the need for careful assessment planning, as more precise assessment methods can increase the workload for course staff. Manual checks are still necessary despite the implementation of automatic systems. The previous pass/fail grading system, while ensuring uniform learning, posed challenges in managing missing assignments and caused prolonged course completion. The new course addresses these issues through a wider grading range, recognizing that students may have diverse learning preferences.

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Digitalisation as an Opportunity for Women in STEM: Researching the Nexus of School, University and Labour Market

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Conference Key Areas: *Equality Diversity and Inclusion in Engineering Education, Recruitment and Retention of Engineering Students*
Keywords: *gender, mechanical engineering, Germany, digitalisation, study programme choice*

ABSTRACT

In Germany, women are still dramatically underrepresented in the fields of STEM, especially in engineering: less than 25 percent of engineering students are female. Correspondingly underrepresented are women in engineering positions, too. Research has shown that diversity in the work force is crucial to develop successful solutions for a complex and sustainability-oriented world.

Therefore, our ongoing research project (01FP22M01), funded by the Federal Ministry of Education and Research (BMBF), focusses on the underrepresentation of

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women in STEM, especially in mechanical and plant engineering. Using mixed methods of qualitative interviews and quantitative online surveys with female pupils, students and employees, as well as industry representatives, to create a comprehensive and multi-perspective picture of the conditions of engineering education and jobs. Thus, we can show what enables or hinders the recruitment, networking and initiative of women in engineering.

This practice paper therefore highlights the environment of engineering education and professional formation along the life course and the application of educational concepts in the light of digitalisation. However, because the research project is currently at the stage of implementing the survey and interviews, first empirical results are not yet available. Therefore, this paper will present the research project’s background, the methodological approach and nonetheless focus on digitalisation and conceptualises how to shed light on the use of digital technologies in engineering education and professional development throughout careers.

1 INTRODUCTION

1.1 Underrepresentation of Women in STEM

The proportion of women[2] in STEM[3] subjects, particularly engineering and computer science courses that are central to mechanical and plant engineering[4], remains low and is rising only slowly (Statistik der Bundesagentur für Arbeit 2019; Jeanrenaud 2020, 8–23; Destatis 2021a). At the same time, mechanical and plant engineering is a key industry for Germany in which enormous disruptions due to advancing digitalisation processes (cf. Kagermann et al. 2013) can be observed and are still expected (cf. TCS 2017). This is why these subject groups electrical engineering/information technology, computer science and mechanical engineering/process engineering are of particular interest.

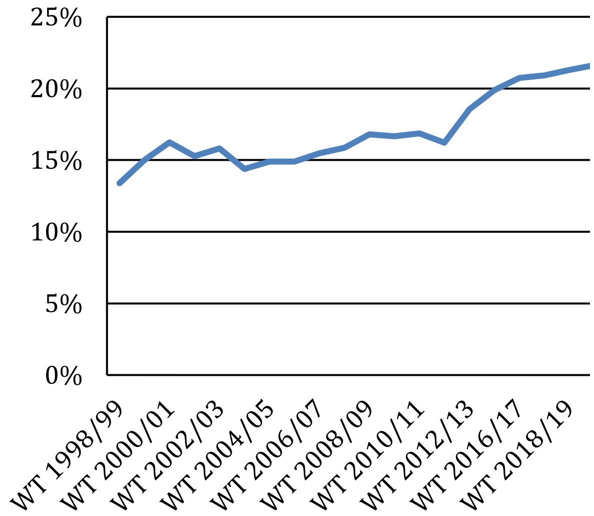

Fig. 1. Women's Proportion Among Female First-Year Students for Mechanical and Plant Engineering[4]

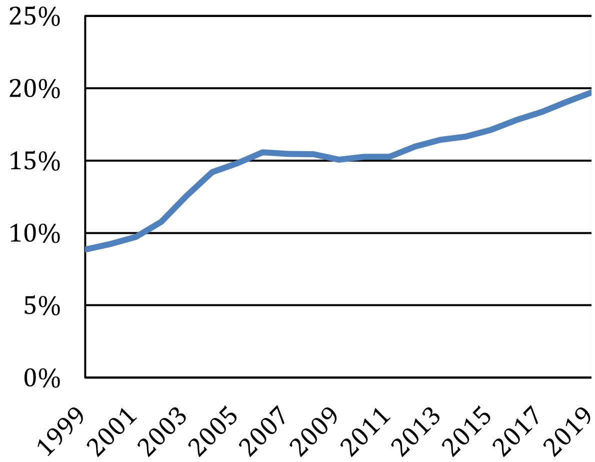

Fig. 2. Women's Share of Successfully Passed University Examinations for Mechanical and Plant Engineering[4]

While the proportion of women in the first semester of the subjects in question (Fig. 1) has risen from 13.39 percent in the 1998/99 winter term to 21.62 percent in the 2019/20 winter term (Destatis 2021a), there has also been an increase in the proportion of women passing university examinations in these subjects (Fig. 2) from

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[2] Even though gender is not exclusively thought of in binary terms on a theoretical and empirical level, but rather takes on ambivalent self-attribution and attribution to others as a structuring social category. Women are spoken of here in order to make this category tangible in terms of social and labour market policy. Thus, when we speak here of gender categories such as women and men, we are referring to persons in empirical data as well as theoretical considerations who define themselves as such (situationally and performatively, temporarily if necessary) (cf. Bereswill 2014).

[3] STEM is understood as abrvearion for the subects of Science, Technology, Engineering and Mathematics

[4] Following (Thomsen, Schasse, and Gulden 2020), these are the five subject groups in the subject classification of the German Federal Statistical Office (2020): Engineering, general (61), mechanical engineering/process engineering (63), electrical engineering/information technology (64), transport engineering/nautical engineering (65) and computer science (71). All together this group contains 46 subjects.

8.8 percent in 1999 to 19.73 percent in 2019 (Destatis 2021b). But women engineers in mechanical and plant engineering continue to be underrepresented even compared to STEM subjects as a whole, which have more than 26 percent of first-year students and STEM degrees in women's hands at more than 31 percent (Jeanrenaud 2020, 8–12).

However, a significant dropout of female graduates into other occupations and inactivity can be assumed, as Thomsen et al. (2020, 20) showed: only 18.5 percent of female graduates were found in a core occupation of production and manufacturing about twelve to 18 months after their engineering degree. This is despite lower dropout rates than men (Thomsen, Schasse, and Gulden 2020, 13; Destatis 2021b).

This in turn means that women are still not participating to the same extent as men in the shaping, employment and acquisition prospects and the growth in importance of digitalisation in mechanical and plant engineering, which is not only problematic from an equality perspective, but is also becoming increasingly difficult for Germany as a business location with regard to the specific STEM skills shortage (cf. BDA 2020). Because STEM professions in general, and especially core professions in mechanical and plant engineering, are of particular importance in the course of the accelerated digitalisation of many areas of society – industry, work, education, social life (cf. Frielingsdorf 2019). Such are STEM studies themselves (cf. Anger, Koppel, and Plünnecke 2016), it is particularly worthwhile to take a closer look at women's choice of field of study and career entry explicitly against the backdrop of trends and changes with disruptive potential for the mechanical and plant engineering industry as a core STEM sector (cf. Orendi 2019) in terms of an analytical looking glass.

Because it can be assumed that the underrepresentation of female engineers in mechanical and plant engineering is due to both cultural and structural causes (Jeanrenaud 2020, 22–30), the research methodologically lends itself both to a look at individual career and life trajectories and to linking these to social and organisational contexts. Therefore, the basic principles and framework conditions are to be analysed with regard to the sustainable recruitment of women for STEM professions in research and innovation.

1.2 Project’s Goals

The aim of the project is therefore to develop recommendations for action for industry, science and politics in order to be able to react in an empirically sound manner to the underrepresentation of women in STEM fields (cf. Jeanrenaud 2020) and to identify which support services, especially for SMEs as well as schools and universities, could be specifically designed for this purpose. In this way, a cultural change should be initiated and promoted in the long term, which will bring more female STEM graduates into industrial companies and anchor them there in the long term, also taking into account the diversity of the special life situations of women.

Therefore, not only the active study choice orientation of female pupils should be reflected, but also the choice of female STEM students should be surveyed and analysed retrospectively. Furthermore, the question of factors in the course of STEM studies and in the transition to professional life is also in the focus of the project. Therefore, female STEM graduates are to be considered. This enables systematic access to the framework conditions in STEM professions and study course selection processes, which can be used to analyse the factors for successful recruitment, networking and successful anchoring of women in mechanical and plant engineering as an exemplary STEM core industry.

To this end, the following questions will be examined:

1. Where is the drop-out: why do below-average numbers of female graduates from engineering core subjects and computer science find their way into mechanical and plant engineering? At what point in the pathway and how do they get lost?
2. How do women engineers decide on specific courses of study, different companies and industries in the age of advancing digitalisation?
3. In this context, it is particularly interesting to see what role the design of the recruiting process plays (from university and company presentations to job advertisements and on-boarding, etc.).
4. What opportunities do digitalisation and other disruptive topics (e.g. new work, cf.Tarnoff and Weigel 2020) present for the mechanical and plant engineering industry (Orendi 2019) to attract more women engineers?
5. What is the role of (company) training in the course of talent retention and management? Studies (cf.Ebner and Ehlert 2018) indicate that, contrary to common assumptions, these have the potential to reduce churn and thus create individual career stability.

In order to be able to comprehensively research these questions, a mixed-method approach of qualitative and quantitative empirical methodology is particularly suitable (cf.Helfrich, Bollier, and Heinrich-Böll-Stiftung 2015; Johnson, Onwuegbuzie, and Turner 2014; Burch and Heinrich 2015). Further specific questions and sub-dimensions will probably be differentiated in the concrete preparation and in the course of the study.

Therefore, vectors and approaches for measures and projects to increase the proportion of women in STEM fields of particular importance for future-oriented and demand-oriented research and innovation, namely electrical engineering/information technology, computer science and mechanical engineering/process engineering, will be identified and condensed on a theoretical and empirical basis. These are based on the current state of causal research and suitably tailored empirical studies. Subsequently, appropriate measures as well as needs for action and, if necessary, further research, will be identified, which equally take into account the diversity of women's life situations, can be used multidimensionally and are correspondingly promising.

2 METHODOLOGY

2.1 Empirical Concept

Based on the goals and questions of the project, it is necessary to focus the study on empirical research into the transitions from school to university and from university to work and the change of jobs and/or companies in the course of life. The primary objective is to investigate the decision-making processes that speak in favour of or against a particular job in mechanical and plant engineering for female engineers.

Since cultural and structural reasons for this are the focus of the research interest, their effects on individual occupational and career paths will be ascertained by means of qualitative, problem-centred guided interviews (cf. Kurz et al. 2009; Witzel 2000; Meuser and Nagel 2009, 2018) with female students and engineers. Digitalisation should always be included as a cross-cutting theme and the question should be linked to it of what it changes in relation to (professional) decisions, careers, fields of activity and opportunities for female engineers. Furthermore, the attractiveness, opportunities and limitations of new work and working time models for female engineers (cf.Pugh 2017), which are further promoted by advancing digitalisation, should be addressed and evaluated in the interview. At the same time, the perspective of the companies should not be neglected, which is why a survey using a standardised online questionnaire of people in management positions from industry is also planned.

The interviews take place by (video) telephone with five cohorts of approximately ten persons each who are pursuing or have completed a university degree in a STEM subject relevant to mechanical and plant engineering and with a particularly low proportion of women.

The five cohorts of female engineers (I to V) are oriented to the time of the beginning of the study and, like the contact persons of the companies (VI), are recruited via a snowball system of various actors in the field (Schnell, Hill, and Esser 2018, 249) (associations, universities, female engineers/networks, etc.). In order to obtain a representative picture of the mechanical and plant engineering industry in Germany, approximately 380 responses from the approx. 21’600 companies nationwide (VdVC 2021) should be sought for a simple stratified random sample ($e = 5.0, z = 1{,}96$).

In order to obtain a picture of STEM women that is as diverse as possible, attention is paid to geographical, subject-related and biographical aspects (migration, proximity to education of the parental home, etc.).

2.2 Interview Cohorts

Empirical cohorts for the interviews are planned in five cohorts (I to V):

I. Schoolgirls in the process of choosing a course of study (approx. 17 years old)
   The main focus here is on study orientation motives, role models, the influence of gender roles and stereotypes.

II. Female STEM students (first / second semester)
Finding one's way in the degree programme, dropout and transfer issues as well as academic success are central to these interviews.

III. Advanced female STEM students (fifth / sixth semester)
These interviews focus on academic success, career planning and shaping one's life.

IV. Female STEM graduates (approximately one year after graduation)
Here, experiences of the transition from study to work, finding a job, aspirations and ambitions, life planning and the associated impressions are still very fresh and therefore the focus of research interest.

V. Young professionals
Approximately three years after STEM graduation. There are good opportunities for job mobility here, as 50 percent of male and female engineers are likely to have changed jobs for the first time after about 24 months, women even more often than men (Ambrasat et al. 2011). The women here are on average still under 30 years old and in the "rush hour of life" (BMFSFJ 2012). The issue researched here is the sustainable anchoring in the STEM profession.

Furthermore, the project deems it necessary to include the companies' perspective within the fields of mechanical engineering and plant engineering.

VI. Company perspective.
For this purpose, contact persons in management positions from companies will be interviewed in order to ascertain their perspective on the questions and topics as well as on the basis of the first interim results arising from the interviews of groups I to V. The interviews will be conducted in the form of a questionnaire. In this context, importance is attached to differentiating between different regions (e.g. east/west, rural/urban environment), company size (international groups/SMEs, family businesses and various central branches of mechanical and plant engineering, which is significantly facilitated by the quantitative survey.

This compilation of data creates the most diverse empirical perspective possible within the constraints of a project's duration of 36 months on the choice of study and the career entry and retention of women in mechanical and plant engineering, as well as on the diverse effects of changes in the world of work.

The interviews are each designed to last between 60 and 120 minutes. This time span allows for an in-depth empirical examination of the complex topics of the study. At the same time, it is reasonably easy for the participants to fit into their daily routine. A total of approximately 50 interviews will then be transcribed and analysed using the method of Qualitative Content Analysis (QIA) (cf.Schreier et al. 2019; Schreier 2014) according to Philipp Mayring (cf. 2016) / Udo Kuckartz (cf. 2016). The analysis software MAXQDA[5] is used for this purpose (cf. Steinke 2007). The open source software Limesurvey[6] is used for the online survey of companies in the mechanical and plant engineering sector.

3 DIGITALISATION AS INTERVENTION

In order to shed light on the environment of digital and traditional engineering education along the life course as well as the application of digital educational concepts and practices, it is necessary to reflect on if and how digitalisation can be understood as a way to improve the participation of women in STEM. Therefore, the project aims to conceptualise digital practices in terms of tools (e.g. Zoom, MS Teams, Cisco WebEx etc.) and learning contents (e.g. open education resources – OER, acquisition of skills to use the digital tools etc.) as an intervention into pedagogical contexts. For the project's point of view, it is necessary to highlight learning in the digital context in higher education institutions as well as on the job.

The extent to which these digital practices and learning contents can be understood as a critical intervention, as a short-term external influence on autopoetic systems that can mitigate or redirect exclusions and repulsive effects for women in STEM, must be explored further. This is ought to shed light on the question of how digital practices enable more diverse lifestyles in STEM professions, too.

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Improving Teaching Quality in Higher Education: A Practitioner's Guide to Using Formative Teaching Analysis Poll

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ABSTRACT

Teaching Analysis Poll (TAP) has become an increasingly popular tool for evaluating teaching quality and enhancing student learning outcomes in higher education. It requires, however, additional human resources. This paper presents a modified version for easy implementation: Formative Teaching Analysis Poll (FTAP). It can be used by an individual educator and is nonetheless an effective practical method for practitioners in higher education to improve their teaching quality and enhance the learning experience of their students.

Based on a review of literature and personal experience using FTAP, in this paper we provide an overview of the underlying methodology of FTAP, its benefits, and how it can be effectively implemented in higher education. FTAP involves collecting formative feedback from students on various aspects of teaching and learning methods, formats, and quality. It may include instructional methods, course design, and student engagement. The collected data is then analysed to identify areas of improvement and to inform teaching practice.

This paper highlights the benefits of FTAP for educators, including the provision of valuable feedback and means to implement it into an ongoing course. FTAP not only contributes to enhance teaching performances but is a powerful instrument to involve students and learners in the design and creation of a learning environment based on their needs. Illustrated with a case example, we show how by actively engaging in the learning process students reflect on their individual needs and take ownership for their education. In conclusion, this paper provides practitioners in higher education with an experience based, practical guide to evaluate their pedagogical and didactical approach, improve teaching quality, and enhance student learning experiences.

1 INTRODUCTION

Current developments in engineering education have taken more account of the nature of professional activities in engineering. As Hadgraft (2017) shows, this is reflected in a paradigm shift in curriculum development away from 'first teach the fundamentals' towards 'start by engaging with the engineering problems'. On the didactical level, this development follows the 'shift from teaching to learning' (Barr and Tagg 1995) and strengthens student-centred teaching approaches (van den Beemt, van de Watering, and Bots 2023; Hadgraft and Kolmos 2020). Putting students at the centre means granting them greater self-determination and a higher degree of autonomy in the learning process. They do not determine what they learn, but how they learn in order to become mature learners (van Uum and Pepin 2023; Wright 2011; Jones 2007). At best, this is reflected in assessment and feedback, which is not summative but formative (Hoidn 2016).

For educators, another question arises: How can we ensure that teaching addresses the needs of learners? In other words, how can we continuously evaluate whether pedagogical and didactical goals are being achieved?

As a method for interim evaluation, the use of a Teaching Analysis Poll (TAP) has gained relevance since 2010, especially in German-speaking countries (Franz-Özdemir, Reimann, and Wessel 2019). In the following, we present this method and in particular address the obstacles to its implementation. On this basis, we make a proposal on how educators can implement this method in a low-barrier way. We argue that our modification as Formative Teaching Analysis Poll (FTAP) is particularly suitable to accompany engineering courses in higher education. We show this by means of an example and derive recommendations for action when implemented by engineering educators.

2 FORMATIVE TEACHING ANALYSIS POLL

2.1 Teaching Analysis Poll

Teaching Analysis Poll is a qualitative method for the interim evaluation of a course that focuses on learners and their learning process. Unlike quantitative, educator-centred final evaluations, TAP allows the results to be integrated into the ongoing course and to initiate adjustments in the conception or choice of methods (Stockmann 2016). An external person is involved in the implementation, e.g. from the evaluation department of the university. This person takes over moderation in the following three-stage process and is required because the educator must be absent during the first phase. In this first phase, the moderator leads a group discussion among learners, which is structured by the following three questions:

1. What aspects of this course help you learn? Please be specific.
2. What aspects of this course impede your learning? Please be specific.
3. What suggestions do you have for improving your learning in this course? Please be specific.

The results are then prioritised by learners and prepared by the moderator for the second phase.

The second phase consists of an evaluation discussion between educator and moderator. During the third phase, learners and educator discuss the results and, if necessary, derive measures for the remainder of the semester. These may also be documented in an agreement (Franz-Özdemir, Reimann, and Wessel 2019; Weiß 2019).

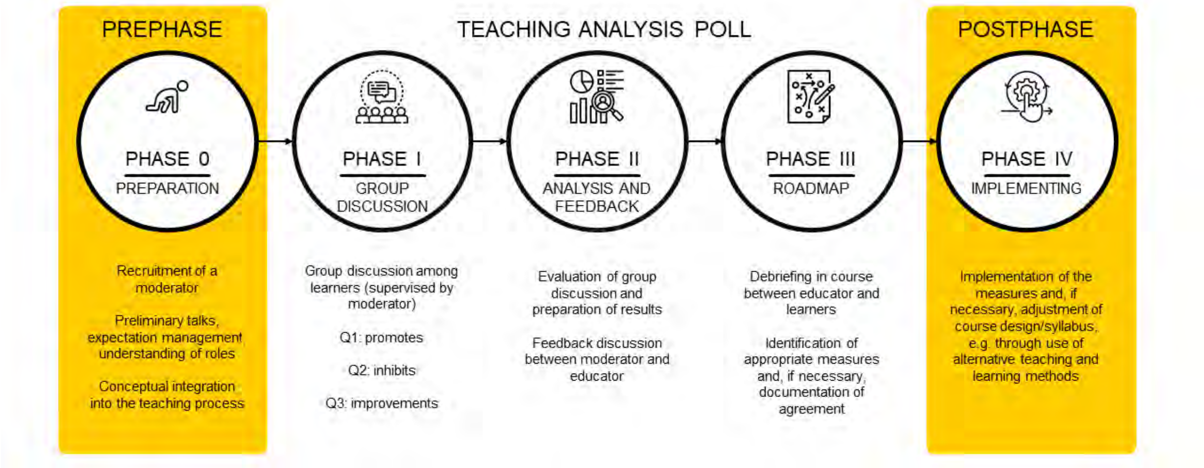

Fig. 1. Phases of Teaching Analysis Poll

Advantages of this method are obvious. It allows educators to assess their pedagogical assumptions and didactic concepts against the actual learning processes of their students, to identify needs for action and to derive measures. At the same time, this method lowers barriers for students to criticise because they do not have to fear being sanctioned for their criticism due to the involvement of a moderator as intermediary and absence of the educator during the discussion. After all, the educator is usually the same person who assesses learners' performances. Another advantage is that students are seen as equal partners in teaching and learning processes and are also given responsibility for successful design (Franz-Özdemir, Reimann, and Wessel 2019).

On the other hand, this method imposes high demands on the implementation, which can pose considerable obstacles. The biggest obstacle is undoubtedly finding a person to function as moderator. Although the literature consistently refers to institutions entrusted with quality assurance in teaching (Franz-Özdemir, Reimann, and Wessel 2019; Weiß 2019; Frank, Fröhlich, and Lahm 2011), human resources in particular are limited in these institutions as well. In our own university, for example, we approached various bodies and, despite numerous requests, were unable to recruit a person to moderate. This experience was decisive for the adaptation of the method as proposed in this paper. Another obstacle is the fact that this method requires an interruption of the syllabus in the ongoing semester. This makes sense from a conceptual point of view but can lead to undesirable interruptions particularly when educators apply student-centred teaching methods. For example, interruptions in the work on a problem-based project can lead to undesirable effects for the learners, of which a lack of commitment to the TAP may be merely the most obvious effect. For educators, these interruptions require a strict adherence to their semester planning, syllabus, and a reduction in content. Accordingly, educators need to be convinced of the benefits of the method, which in turn can be an obstacle for first-time implementation. Finally, we observe a limitation of the method in the one-time intervention. Due to the high effort involved, TAP does not allow for iterations and therefore does not permit any statements about the effectiveness of the measures taken subsequently.

2.2 Development of Formative Teaching Analysis Poll

We responded to the obstacles for implementing TAP and adapted the method to be able to use it in a more accessible way. The following six criteria were decisive:

1. Implementation of TAPs should not depend on the availability of (human) resources outside the course.
2. The method should be formative. Here, we understand formative evaluation as an evaluation process that goes beyond a one-time intervention.
3. The method should be applicable without interrupting ongoing learning. Thereby we want to ensure that learner-centred methods can unfold their didactic potential unhindered. We argue that student-centred methods benefit more from accompanying reflection than from interrupting evaluation. This makes the method suitable for use in a variety of engineering education courses.
4. The method should also be able to reflect and evaluate adjustments made based on prior feedback. Its accompanying character should enable educators to institutionalise it as an iterative process.
5. Educators must ensure that students are involved as equal partners in designing the learning environment and are taken seriously as experts for their (respective individual) learning processes.
6. To avoid censorship effects by not using an external moderator, there must (also) be a channel for anonymous feedback.

For TAP to fulfil these criteria, we had to find a way to integrate an evaluation not only as interim evaluation, but also as an accompanying process with the teaching and learning process. Here we coupled the method with another format, a learning journal. A learning journal is a written documentation of one's learning process that emphasises reflection on learning over the content learned (Park 2003; Johannsen 2021). Although we provide guiding questions for learners, we do not specify content or length of entries. For educators, we recommend using a digital tool because it allows asynchronous access to content by learners and educators alike. In addition, it features methodological overlaps with TAP. Using it as part of a FTAP is unique in that the questions of a TAP concerning (1.) helping, (2.) impeding, and (3.) improvable aspects are integrated here.[2] This allows educators to obtain feedback on each past session before the next one. Any other individualised feedback tool is, of course, equally suitable if it is used regularly by learners and evaluated by educators. Web-based instruments that allow anonymised data entry are particularly suitable for this purpose. Alternative easily used tools include ether pads or online whiteboards. All that needs to be ensured is participation to such an extent that the results can neither be individualised nor become meaningless due to the low number of contributions.

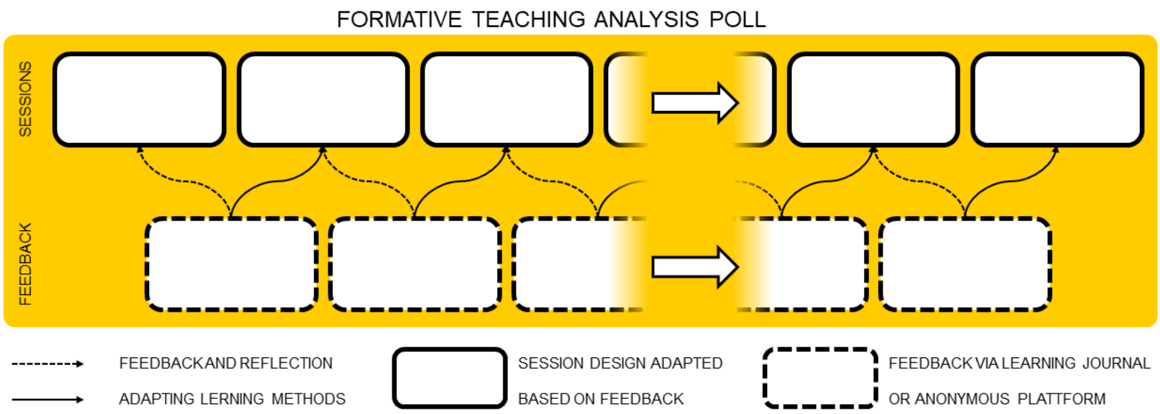

Fig. 2: Iterating Phases of Formative Teaching Analysis Poll (here in combination with Learning Journal)

Results can then either be systematically evaluated or used as a channel to pragmatically identify any need for action. Either way, each analysis should be based on a methodological approach. Due to reduced effort and with the aim of creating the best possible learning environment, especially when teaching and learning methods are used in which an educator has little experience, there is much to be said for the latter, pragmatic evaluation. In our experience, the time needed for each weekly evaluation is about one hour for a course with thirty learners. This is a reference value from which individual variations are possible. We found that it is good practice to always select the most important results at the beginning of each session and report them back. This allows learners to correct misinterpretations and to think about improvements on their own. They also experience that their contributions (can) have consequences for their own learning process. By making feedback loops an integral part of the course, the process character of FTAP is considered. In a final session reserved for discussion and reflection, we reflect on the course. As part of this reflection, an evaluation of the FTAP also takes place. We provide an insight into these results under 3.1 in the context of the case example. In addition, we conduct a summative (and therefore educator-centred) final evaluation. It is, of course, optional to use the final session in this way as it is optional to conduct an evaluation at the end.

[2] TAP can also be combined with management methods such as the stop-start-continue approach and made productive for higher education teaching (Hoon et al. 2015).

2.3 Evaluation

To investigate whether FTAP is effective and achieves the goals we set, we used the example of a course offered every semester and conducted a group discussion in the final session for a preliminary evaluation. As this session did not focus on the FTAP method, but rather reflected on the course, we decided to conduct a qualitative analysis. We evaluated the results of group discussions as well as entries from learning journals and anonymous feedback channels using a qualitative content analysis based on (Gläser and Laudel 2013). This analysis includes the contributions of eighty-seven learners. Because this paper is a practical report, we will limit subsequent comments to a poignant presentation within the framework of the following case example using illustrative statements. This also results in limitations of this evaluation, given that the focus is on FTAP and its implementation strategies.

3 IMPLEMENTATION

3.1 Case Example

FTAP was applied and evaluated in the course *Engineering for Impact*. It is an interactive seminar in which students use transdisciplinary methods to develop innovative, technology-based solutions for societal challenges. We use a variety of formats and methods to establish a practical relevance and to pave the road towards application in the spirit of the beforementioned paradigm shift in engineering education. Most notably is an involvement of guest experts from practice, who hold workshops with students in which they apply methods and tools to further develop their respective projects. As part of the assessment, students write a paper describing the problem in a scientific way and explain their solution in an oral presentation. As part of the assignment, they reflect on the social impact, identify stakeholders from the fields of science, business, society as well as politics and develop a communication strategy with suitable measures for implementation. We have published an exemplary demonstration in cooperation with Fraunhofer-Gesellschaft (Johannsen and Schraudner 2022).

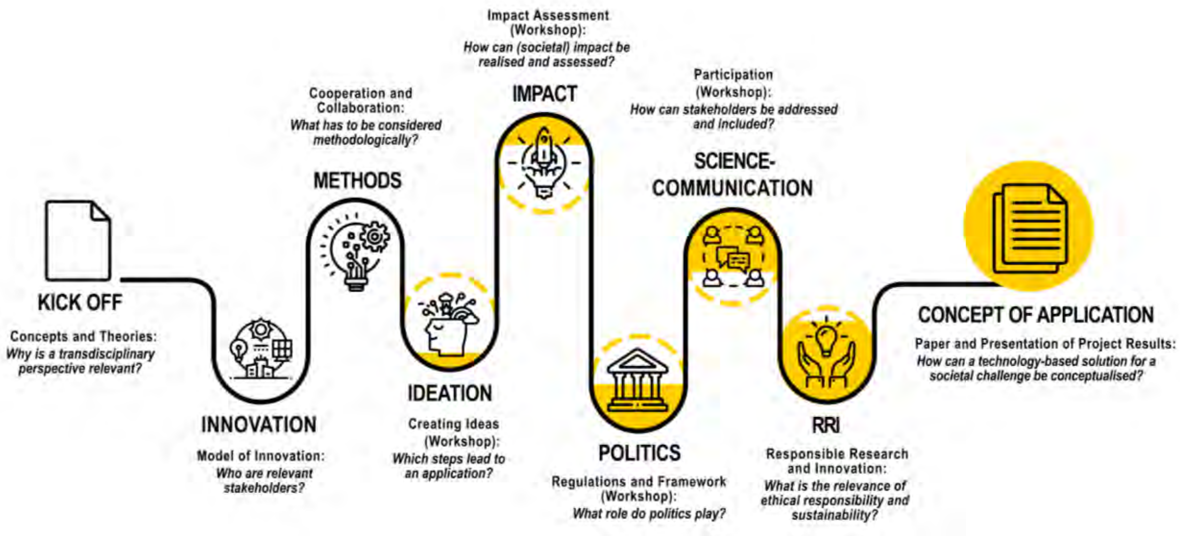

Fig. 3: Simplified Syllabus of this Case Example

Feedback we received from students we interpreted against the background of their project work. Overall, the evaluation has resulted in various clusters, three of which we present here as examples. In the following figure, the clusters are named and then illustrated with the students' own statements. All translations are our own.

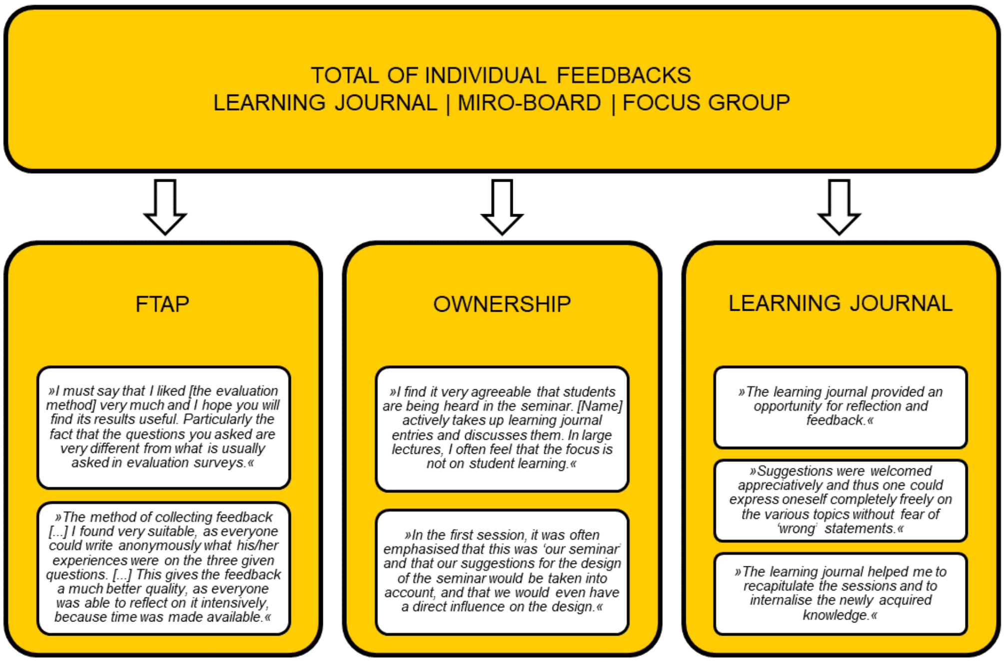

Fig. 4: Selected Results of Qualitative Evaluation with Exemplary Statements

The first cluster concerns FTAP, which is the subject of this paper. It is not an independently evaluated object, so not all students refer to this format. Nevertheless, it was repeatedly taken up and, above all, the inclusion of feedback in the course was a constructive contribution to its design. This is exemplified by the first statement, in which a student emphasises its usefulness. The second quote refers to the possibility of giving direct but anonymous feedback. Here, the contribution emphasises the quality of the feedback, which benefits from this integrated format because it makes it easy to accept it as an integral part of the course. As a result, students recognise its benefits, develop reflective capacities, and engage more willingly in reflective activities. This is in line with results of Power and Tanner (2023).

The second cluster refers to the role of students as co-creators of the course. The first quote highlights the function of learning journals as a channel for feedback for the design of a supportive learning environment by using feedback in iterative cycles to adapt used methods and formats in the course to needs of learners. While this quote is taken from a retrospective point of view, i.e. at the end of the semester, the second quote is taken from an entry in a learning journal following the first session at the beginning of the semester. It emphasises the importance of involving students from the beginning, taking them seriously as experts for their learning and sharing responsibility for designing their learning environment. Our results, hence, are in line with results of similar approaches (Zhang 2022).

A third cluster provides exemplary quotes about using learning journals as a format. We chose to present these results, because it played a key role in our conception, although it is not necessary for the implementation of an FTAP and can be replaced by other channels. Its particular benefit arises from the fact that students not only provide feedback, but are also given supporting structures, for example through guiding questions, which help them to achieve a more sophisticated level of reflection, both in terms of a critical appraisal of the content as well as the pedagogical and didactical framework (Hatton and Smith 1995). Here, too, appreciative interaction and a high degree of transparency about adjustments in the course helped to improve the learning environment, promote learning successes, and thus contribute to better results in the course overall. Transparency not only includes the implementation of measures, but also a justified rejection of student suggestions if these cannot be implemented.

3.2 Recommendations for Action

The path to this innovative, formative teaching evaluation can be taken without much effort. Those who want to introduce FTAP in their courses merely need time within the course, and willingness to engage in criticism, and make adjustments in collaboration with learners to improve their learning environment. We conclude by summarising our recommendations for educators who want to go down this path and plan to use FTAP in engineering education.

1. This format is based on voluntary participation of both educators and learners and serves the purpose of aligning expectations and needs of educators and learners alike. Handle results with due confidentiality.
2. Be prepared to (partly) give up control and share responsibility with learners.
3. Allow time not only to take in learner feedback but also to discuss it with them and derive appropriate adjustments from it.
4. Find a format that is compatible with the learning management systems (LMS) currently in use and does not require any additional preparation on either the educator's or the learners' part.
5. Be appreciative and take learners seriously as experts for their learning process.
6. Be transparent about both the changes you implement and the suggestions you discard.

Our experience is in line with Frank, Fröhlich, and Lahm (2011) that educators who show a sincere interest in successful learning in their course and who approach establishing an appropriate learning environment with scholarly curiosity benefit the most from FTAP. In this respect, it is a matter of attitude, because those who are as ambitious about investigating ways to improve their teaching as they are about their own research are embarking on the wonderful journey of improving engineering education together with learners through FTAP.

4 SUMMARY AND ACKNOWLEDGMENTS

FTAP is a method that allows formative evaluation of courses and provides formative feedback for educators, stimulates reflection, and promotes exchange between educators and learners to create a supportive learning environment and to increase learning success. Thereby, it can be ensured that education effectively addresses needs of learners as well as achieving pedagogical and didactical objectives. Considering that engineering education is undergoing a paradigm shift with more student-centred teaching and learning approaches, this ongoing alignment is of great importance. Therefore, FTAP is particularly suitable for educators who want to adapt their teaching and experiment with new formats, because it contributes to quality assurance with its iterative and agile stages.

Our special thanks are extended to the participants of the course *Engineering for Impact* at Technische Universität Berlin for their cooperative, open, and constructive participation, through which we learned with and from each other.

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A survey to evaluate laboratory activities across an undergraduate engineering degree programme: data from five years showing repeatability and sensitivity

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ABSTRACT

Laboratory activities are an essential part of an undergraduate engineering education. This paper focuses on evaluating the student experience of laboratory activities. We present a laboratory-specific survey used with large cohorts of students (200) about laboratory activities across an undergraduate Mechanical Engineering degree programme. The key question we try to answer is whether the results of the survey can be used to inform teaching decisions such as which activities need improvement; how to improve them; and to validate these interventions.

We present nine common questions that were used to evaluate activities across a programme. We present five years of data for five of the activites we assess – specifically those from the first year of the programme. The data covers pre-pandemic, lockdown, and post-lockdown periods. The data includes activities that have remained consistent, and activities where changes have been implemented.

For consistent activities, data show good repeatability, adding confidence to the method. The effects of interventions can also be detected. We define a significant change as being a multiple of the standard deviation, across years, when no interventions were used. We discuss the validity of the survey and conclude that, in practical terms, it is useful for informing teaching decisions.

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1 INTRODUCTION

Laboratory activities are an essential part of an undergraduate engineering education. This paper addresses the challenge of *evaluating* laboratory activities. The purpose of a high-level evaluation across a degree programme is as follows. Firstly, to provide evidence of continued high quality to justify maintaining the status quo if applicable. Secondly, to identify opportunities for improvement and hence inform the rational allocation of teaching resource to these areas. For example buying new equipment or paying for staff time to improve materials or processes. In the second case, a closer look would be needed before making decisions; the purpose of the high level survey is to identify where attention is needed. Thirdly, evaluation can validate interventions.

Evaluation can consider different perspectives and stakeholders, for example an assessment of learning gains (Watai et al. 2007, Salim et al. 2013), process (Kotulski 2010), or student views (Stark 2016). The student view has been shown to play an important, if not essential, role in evaluating laboratory activities (Nikolic 2016). This paper presents and analyses a survey to evaluate the student experience of laboratory activites.

In this paper we briefly review literature on student evaluations. We present a survey methodology. Example results from the first year of a degree programme are presented, and we discuss the interpretation, validity, and application of the survey.

2 LITERATURE REVIEW

Student evaluation of teaching (SET) is well studied but controversial. A review by Stark (2016) identified the invalidity of surveys – due to bias – of student *judgement* (such as instructor effectiveness or professionalism), but stated that it may be valid to evaluate a student’s own experience. We therefore avoid seeking to identify e.g. ‘good teachers’, but try to identify good (or bad) ‘experiences’. A good experience is not the same as effective learning but it is a useful proxy that can be considered along with other types of evaluation.

The rich literature on evaluation tends to focus on classroom activities which are distinct from laboratory activities so not directly applicable. Evaluation of laboratory activities in general is challenging because there is also a diversity in the purpose and nature of laboratory activities across different disciplines and institutional cultures (Feisel and Rosa 2005). Despite this diversity, a common approach to evaluation across a programme is desirable for efficiency in deployment across a programme, and for higher utility – such as rational teaching resource allocation within a programme.

A small number of engineering laboratory-specific surveys are described in the literature. Nikolic (2016; see Ch.3, Ch.7 and Table 7-II) developed a common survey for laboratory activities. The survey used six questions, focussed on ‘impression’, content/information, ‘worthwhile learning experiences’, suitability of computers and other equipment, and condition of the laboratory. Repeatability was reasonable, and interventions could be detected. Most questions rely significantly on student judgements.

Corwin et al. (2015) evaluated course-based research experiences in biology, focussing on three dimensions: ‘collaboration’, ‘discovery’, and ‘iteration’. They used a 17 item survey after reducing from a larger bank of questions by testing for statistical validity. The strengths of Corwin et al. (2015) are the statistical validation of the survey; and the identification of key ‘dimensions’, which is a transferable notion and is experience-orientated as opposed to judgement orientated.

In the case of undergraduate engineering education the emphasis is slightly different to the course-based research that Corwin et al. (2015) evaluated so it cannot be directly applied. In this paper we present and analyse a survey that is ‘dimension’ and ‘experience’ orientated like Corwin et al. (2015), but practical in the sense of Nikolic (2016) by having a small number of questions and being applied across a whole programme. The key question we try to answer in this paper is whether the results of such a survey can be used to inform decisions about teaching.

3 METHODOLOGY

We surveyed students using nine standard, closed questions applied to all laboratory activities in their programme. The survey contains supplementary questions that vary year-to-year, and free text comments. In this paper, however, we focus only on the nine standard questions in the survey.

3.1 Nine standard questions

Due to the application of the survey across many activities, we limit ourselves to nine questions to avoid survey fatigue in the students. One student will answer nine questions per activity, for example first year students provide 45 total responses; for our second year students it is 72, which we judge to be a practical limit.

The ‘questions’ are positively worded statements listed in Table 1, answered with a 5-point Likert scale: strongly agree / agree / neutral / disagree / strongly disagree.

Table 1: the nine statements in the 2023 survey.
** = different in previous years; + = clarified from previous years.*

Short name	**Full statement**
Purpose	‘The purpose of the lab was clear to me.’
Conceptual	‘The lab session gave me a better understanding of the abstract concepts taught in the related module (e.g. energy, pressure, stress, entropy, current, resistance, etc.).’
Challenge	‘The lab session challenged me in a positive way’
Tech. comm. skills+	‘Preparing a report/presentation helped me develop technical communication skills’
Documentation and guidance*	‘The documentation and guidance for the lab session was clear, organised and well prepared. Consider: - Handouts, videos, interactive content - Guidance in the live sessions - Using the practical equipment (where appropriate)’
Engagement	‘I felt engaged in the experience and enjoyed the lab session’
Support*	‘I was well supported by GTAs or other staff during the lab session.’
Feedback	‘I received good feedback [link to College page about feedback] When answering this question consider feedback during lab sessions as well as the marks on your final report/presentation.’
Collaboration*	‘I was able to collaborate with my colleagues (to the extent required).’

Table 2: four statements that changed between years, and their previous versions. Multiple versions indicate multiple changes over different years.

Short name	Previously
Technical comm. skills	**Professional skills** – 'The lab session and report writing helped me develop professional skills' (2019,2020) – 'Preparing a report/presentation helped me develop professional skills' (2021)
Documentation and guidance	**Equipment** – 'I understood how the equipment worked and was able to use it as required.' (2019, 2020)
Support	**Motivation** – 'The lab session was motivating.' (2021) **Practical skills** – 'I learned new and useful practical skills' (2019, 2020)
Collaboration	**Knowledge** – 'I learned new things and reinforced what I had learned in the related module' (2019, 2020)

3.2 Selection of questions

The original nine questions were selected as a starting point based on practical experience, i.e. without a theoretical basis. Annual reviews with a team of activity leaders led to action plans, but we also discussed whether questions should be changed. The changes we made are given in Table 2 and are discussed here briefly.

A survey question about using equipment was refined to focus specifically on documentation and guidance – because this feedback is more actionable for teachers. A question about gaining knowledge overlapped with the question about 'conceptual' understanding, so was replaced by a question focussing on collaboration – a topic that we had previously omitted but was particularly sensitive during lockdown. The question about support reflects a growing focus on the support staff – typically PhD students – and replaced a question on 'motivation' which showed a strong correlation with 'engagement' so was judged to be redundant.

The nine themes that we present here partially correspond to dimensions that have been used in the literature. For example, collaboration (Corwin et al. 2015) and challenge (Kandiko Howson and Matos 2021) are common themes. There is a difference in the overall collection of themes used here because the focus is on discrete activities and on the laboratory. It would require further research to provide a rigorous justification for our 'dimensions'. Currently they have emerged from practice.

3.3 Analysing repeatability and sensitivity

Likert scores, s, range from 1 to 5. For large samples we can consider mean (average) values, μ, of the Likert scale (Derrick and White 2017, 2),

$$\mu = \frac{1}{n}\sum_i^n s_i \qquad (1).$$

where n is the number of responses and i is an index spanning all responsess. We also take an interest in the 'mean of means' μ_2 across years or across the dimensions of an activity. To analyse the repeatability, we consider the standard deviation, σ, of the values of μ over a range of m years:

$$\sigma = \sqrt{\frac{1}{m-1}\sum_j^m (\mu_j - \mu_2)^2}, \qquad (2).$$

where j is the year. More sophisticated approaches, such as omitting neutral responses, and other more advanced filters, did not have a significant effect on the results hence we use the simplest approach – given here – for clarity.

When the difference in the mean, between cohorts or between activities, is greater than the standard deviation ($\Delta\mu \gg \sigma$) we consider the student experience to have changed significantly, as opposed to there being variation between cohorts and/or due to sampling. 'Sensitivity', which is the smallest change, $\Delta\mu$, we can detect above the noise, is therefore an arbitrary multiple of σ, for example 3σ is a practical threshold.

3.4 Context

The survey was optional and anonymous for students and conducted in May each year after all the relevant activities were complete and feedback had been delivered. We conducted the survey from 2019 onwards and present data from 5 consecutive years. Response rates are given in Table 3. For brevity in this paper we only analyse activities from the first year of study. All activities were in-person except in 2021 when they were remote. The survey was conducted at a time when students could socialise, except in 2020 and 2021 when students were in lockdown while filling out the survey. During lockdown (2021) each activity was adapted to remote conditions differently, as summarised in Table 4.

Table 3: response rates and cohort sizes in the survey over five years.

2019	2020	2021	2022	2023
127/174 (73%)	89/172 (52%)	112/214 (50%)	74/199 (37%)	118/194 (61%)

3.5 Description of the activities

All activities involve a scheduled 2-3 hour activity in a laboratory, summarised in Table 4. Some activities involve mandatory preparation work. Most activities involve submitting work a week later to be assessed.

Table 4: Activities in year 1 of study

Activity (subject)	**Purpose and description**	**Lockdown (2021)**
Fairground (solid mechanics)	Introduction to lab work and report writing. Scenario about a fairground ride and drilling a hole. Measure strain on a plate. Write a report.	Data provided
Pipe flow (fluid mechanics, aka 'fluids')	Scenario about a customer complaint. Discovery based learning, testing pipes for pressure drops. Write a report.	'Human robot' in the lab live on Teams following instructions.
Steam plant (thermodynamics, aka 'thermo')	Practical experience of thermodynamic cycles. Measure performance of a steam plant. Consultancy scenatio. Group presentation.	Data provided
Mechatronics	Practical training on a series of DC circuits. Build, test and complete in-lab. Complete before leaving the lab.	Human robot
Materials	Tensile test of aluminium allous; hardness test of carbon steels. Write a report based on a template.	Data provided

4 RESULTS AND DISCUSSION

Fig 1. shows results for five consecutive years, for four of the five different activities in the first year of the programme. The top row of Fig. 1 shows the two higher

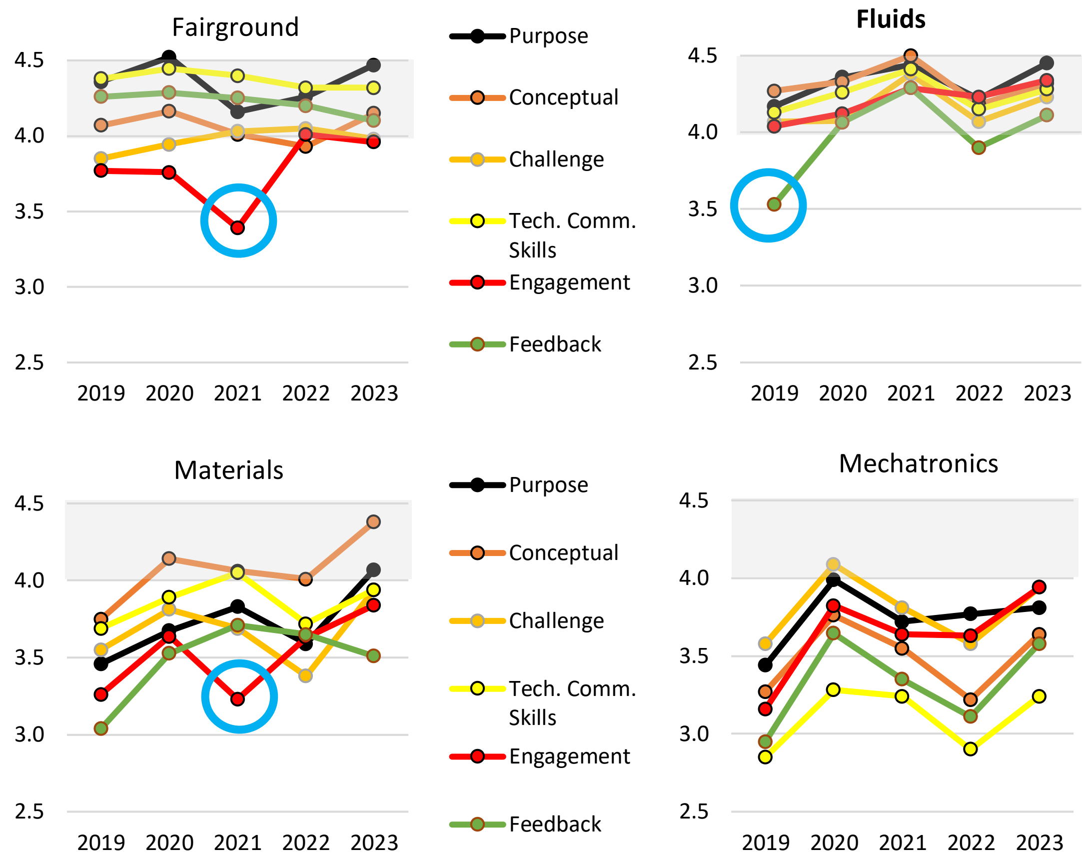

Fig 1. Plots of the mean (μ) in six categories, for four activities, over five years. The legend is the same for all plots. Cyan circles highlight cases for discussion.

scoring activities that were renewed before the survey began. The left column of Fig. 1 shows the activites that provided students with data during lockdown, while the right column shows activities for which the 'human robot' approach was used to acquire data (see Table 4). Further results are provided in Table 5 which includes the standard deviations.

4.1 Repeatability

Consider the 'Fairground' and 'Fluids' activities (top row of Fig. 1, top two rows of Table 5), which both scored consistently high ($\mu > 4$) over the five years. Their standard deviations are $\sigma < 0.15$ in all categories – indicated by green highlights in Table 5 – except two cases, circled in cyan in Fig. 1 and highlighted cyan in Table 5, to be discussed later. The value $\sigma < 0.15$ is significant; for example, a difference $\Delta\mu > 0.5$ between activities or between years is common. Hence variation of the results for these activities is low enough for the survey to be useful in practice.

For the remaining three activities, the standard variation was higher, mostly $0.15 < \sigma < 0.3$. The survey is still useful for these cases, but with lower confidence.

4.2 Sensitivity to difference between activities

The variability for one activity across cohorts (σ), is significantly smaller than the differences in mean scores ($\Delta\mu$) between activities. Perhaps the most obvious result

Table 5: Mean and standard deviation, $\mu \pm \sigma$, for the six consistent questions. Highlights: green: $\sigma < 0.15$, yellow: $\sigma < 0.3$, grey: $\sigma > 0.3$, cyan: notable cases.

	Purpose	Conceptual	Challenge	Tech. Comm. Skills	Engagement	Feedback	μ_2
Fluids	4.3 ± 0.13	4.3 ± 0.12	4.2 ± 0.14	4.3 ± 0.11	4.2 ± 0.12	4.0 ± 0.29	4.2 ± 0.1
Fairg'nd	4.4 ± 0.15	4.1 ± 0.10	4.0 ± 0.08	4.4 ± 0.05	3.8 ± 0.24	4.2 ± 0.07	4.1 ± 0.1
M'tronics	3.8 ± 0.20	3.5 ± 0.24	3.8 ± 0.22	3.1 ± 0.21	3.6 ± 0.30	3.3 ± 0.30	3.8 ± 0.3
Materials	3.7 ± 0.24	4.1 ± 0.23	3.7 ± 0.22	3.9 ± 0.15	3.5 ± 0.27	3.5 ± 0.26	3.6 ± 0.2
Thermo	3.5 ± 0.33	3.8 ± 0.14	3.8 ± 0.18	3.9 ± 0.19	3.2 ± 0.13	3.3 ± 0.10	3.5 ± 0.2

to make this point is for 'Tech comm skills' in yellow in Fig. 1 and the fourth column in Table 5. The mean for the Mechatronics lab, $\mu = 3.1 \pm 0.2$ is at least four standard deviations lower than the lowest scoring of the other activities. This reflects the fact that there is no technical communication in the mechatronics activity – it is a 'build and complete' activity with no assessed report/presentation, while the other four activities have an assessed technical communication. This result validates sensing differences in student experience between activities.

4.3 Validating interventions

The Fluids activity was revised for 2019. The survey indicated that the revision was successful except for feedback, identified in cyan in Fig 1 and Table 5. An intervention was implemented in the following years: feedback sessions between student and marker were scheduled after written feedback had been provided. This practice was copied from the Fairground activity, and the feedback score for the Fluids activity subsequently increased and remained high. The increase of $\Delta\mu = 0.50$ was $> 3\sigma$ in the following four years, which validates the intervention.

A second intervention was in activities that were adapted during lockdown – see Table 4. The left column of Fig. 1 shows activities where data was provided *a priori* to students. Significant drops ($\Delta\mu \approx 0.4$) in engagement (red line) with are evident, and are identified in Fig. 1, left column, by cyan circles. The right column of Fig. 1 shows where a 'human robot' was used to give students agency and interactively gather data. In those cases there is no drop in engagement. The survey provides evidence that a 'human robot' approach was more engaging that providing the data.

The Materials and Thermodynamics labs were subject to many smaller interventions over the years, which may explain the large variations. The Mechatronics lab was essentially the same over five years, so the larger variations for that activity are harder to explain.

5 DISCUSSION

Three aspects of the work presented are discussed here in more detail. Firstly, an interpretation of the results and some clarifications on their meaning. Secondly, a discussion of the validity and limitations of the survey. Finally, some 'use cases' where the results have had an impact on practice.

5.1 Interpreting the results

The relatively low standard deviation ($\sigma < 0.15$) for the two high scoring and consistently delivered activities gives us confidence to attribute larger changes, for example $\Delta\mu > 0.5$, to a change in the student experience. We can in turn, through our wider knowledge of the activities, attribute interventions as causes.

The case of mechatronics illustrates that nuance is required in interpreting the survey. The activity was delivered consistently for five years. The standard deviation was higher ($0.2 < \sigma < 0.3$), but the data in Fig. 1 show that the relative scores of each dimension were consistent. The variation from year to year appears to be uniform (the same for each dimension). In this case, the magnitude of change required in the survey results, before making conclusions with high confidence, is higher. However, the use of relative changes, of a smaller, magnitude can be used in as an alternative metric, albeit with lower confidence.

For any of the survey results, we urge caution when interpreting them. For example the low score in mechatronics for technical communication skills reflects the intent of the teacher. The low score is not necessarily a negative outcome. With this caution in mind, teachers can confidently take action based on the survey results.

5.2 Other forms of validity

Four forms of validity are briefly mentioned here: face, content, criterion, and construct validity. We believe that the face validity of the survey is high because it was developed iteratively through practice and the results are used by practitioners. The content validity is subject to the limited number of questions, for example there are no questions on practical skills. The criterion validity is good in the sense that relative measures are strong, but there is no absolute measure of any of the dimensions. We have not formally considered how students interpret the questions on the survey, but the free text comments and focus groups, combined with our hands-on teaching experience, provide some confidence in this area.

The construct validity of the survey has not been proven statistically. There is evidence in the data that survey results distinguish adequately. Questions were removed when correlations were found. The cases of technical communication skills in Mechatronics, feedback in Fluids, and engagement during lockdown, all support the use of the survey with confidence. This confidence is useful in practice, but it is not a rigorous statistical analysis. The selection of questions is heuristic and would benefit from a more rigorous analysis. Such analysis, however, is likely beyond the scope of this practical survey covering many activities.

5.3 Impact on practice

We use the survey to identify areas where action is needed. We propose an action, identify resources needed to take the action, and indicate *a priori* what changes to the survey results would validate the intervention. We conduct this process as a team across thirteen activities, including the five reviewed in this paper, and another eight in the second year of the programme.

The clearest example of an impact on practice is on the top-right plot in Fig. 1, where a low score for feedback prompted a change to feedback practices and a subsequent, significant, and sustained improvement in the survey scores and follow-up focus groups.

Another example of impact on practice is when an academic member of staff expressed an intention to improve the documentation for an activity. In this case the author advised the staff member not to make the improvement, because the high quality videos they had recently created returned the highest score of any activity in the ‘documentation and guidance’ category – a score which has since been maintained. In this case the impact on practice was to save the opportunity cost of doing work that was unnecessary – despite being well-intentioned.

The final type of example is where staff have targeted an improvement in survey scores with a well intentioned intervention, but that the survey results do not validate the intervention, e.g. the change in score is too small to be significant, or may even be lower. These cases are complex and require deeper analysis than the current survey is capable of supporting. In those cases more detailed evaluation and reflection is required.

6 CONCLUSIONS

A survey containing nine standard questions was used for all laboratory activities across a degree programme. This paper summarised the results from five years of data across five different activities in the first year of an undergraduate mechanical engineering degree programme.

The survey can identify the differences in student experience between concurrent activities and between cohorts. Validated examples include whether technical communication skills improved; the quality of feedback; and the level of engagement. We use the survey in practice to identify areas that need improvement; to validate interventions; and to monitor continued high quality activities.

The strength of the work presented here is its application over five years, and across a programme covering multiple activities. The survey has evolved from practice, which gives it an authenticity and face valitiy, but also limits its construct validity. A statistical validation of the question choice would improve the construct validity.

We will continue to use the survey in coming years, and suggest its wider use across our institution. We would be happy to hear from anyone interested in collaborating on the use of the survey.

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ETHICAL CONCERNS AND RESPONSIBLE USE OF GENERATIVE ARTIFICIAL INTELLIGENCE IN ENGINEERING EDUCATION

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ABSTRACT

The use of educational technologies that use elements of machine learning (ML) and artificial intelligence (AI) are becoming common across the engineering education terrain. With the wide adoption of generative AI based applications, this trend is only going to grow. Not only is the use of these technologies going to impact teaching, but engineering education research practices are as likely to be affected as well. From

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data generation and analysis, to writing and presentation, all aspects of research will potentially be shaped. In this practice paper we discuss the ethical implications of the use of generative AI technologies on engineering teaching and engineering education research. We present a discussion of potential and futuristic concerns raised by the use of these technologies. We bring to the fore larger organizational and institutional issues and the need for a framework for responsible use of technology within engineering education. Finally, we engage with the current literature and popular writing on the topic to build an understanding of the issues with the potential to apply them in teaching and research practices.

1 INTRODUCTION

The contemporary educational sector, including higher education institutions (HEIs), exists in a highly technological state. In addition to traditional applications such as Learning Management Systems (LMS), universities use videoconferencing, automated assessments, and increasingly, Machine Learning (ML) or more generally Artificial Intelligence (AI)-driven applications. From TurnItIn to Grammarly, these new technologies have found broad application including in engineering education. In addition, the data generated by these applications has lead to features that employ Learning Analytics (LA) and Educational Data Mining (EDM) for sensemaking.

The major difference between the newer technologies now in use for education and research and those used earlier, is the generation of data and capabilities that have been developed to analyze analyse and use that data. In recent times, the field of AI has entered a new era marked by remarkable advancements in generative AI applications. One notable example is ChatGPT (Dwivedi et al., 2023), which builds upon the power of Large Language Models (LLMs) (Qadir, 2023). By harnessing the wealth of textual data accessible on the internet, these applications create models with the ability to predict highly probable completions for any given text. As a result, they exhibit language generation and conversational capabilities that closely emulate human-like interactions.

While these technologies have opened up numerous promising applications that align with educational and research objectives of engineering, it is essential for us as a community to address important questions arising from their rapid and uncritical adoption. This collective effort is crucial to ensure their responsible use and mitigate potential concerns. Especially as engineering educators preparing the next generation, we have a moral obligation to think deeply about these issues and reflect on our use of technology across our own practices, as we prepare our students to practice in a world where these technologies exist (Johri et al., 2023; Johri, 2020).

2 ETHICAL CONCERNS

Emerging technologies provide a range of new affordances that we can use in educating future engineers. In deciding how these AI technologies should be employed in our teaching, there are a range of key ethical concerns that we must consider. Scholars in multiple communities, such as LA and EDM, have commented extensively on these issues (Kitto and Knight, 2019; Slade and Prinsloo, 2013; Tzimas and Demetriadis, 2021). Navigating these ethical issues is not always straightforward as often we face dilemmas of conflicting demands of values that we hold. For instance, the use of complex LLMs can improve our ability to make accurate predictions but they also reduce our ability to understand how they work (Whittlestone et al., 2019); the use of generative AI can result in impressive applications but may also result in the loss of jobs and deskilling of humans. In what follows, we discuss some ethical concerns surrounding generative AI and the use of automation in education.

2.1 Data privacy and consent

A fundamental concern with the use of new forms of digital technology is how they handle data – what data is collected, how is it stored and retrieved, where is it stored, and what kinds of consent provisions are available to users. The majority of education contexts where AI is deployed are systems and situations that are intrinsically linked to core operations of the university - situations where students are either not asked to consent, or where refusing consent would be impractical. Opting out of automated assessment is impossible; seeking explicit consent for data mining of historical data is similarly impractical.

Increasingly, developers of educational technology products tend to gather more data than what is functionally needed for potential future use and extensions. This has meant that data have been collected en masse with little regards to their actual use, and data can be repurposed for purposes different from their original intended use. Consequently, consent mechanisms are overreaching in what they ask of users; similar to the “I Agree” most of us click on while accessing most digital platforms – a consent that is in conflict with the GDPRs data minimisation principle.

2.2 Algorithmic bias

A related concern to data is how the data are analyzed analysed and used. Increasingly, systems use ML techniques to make sense of the data. To develop these algorithms, they have to be trained on datasets. These datasets are largely developed through data that are readily, conveniently, available and not necessarily represenative of a specific issue. As an example, to develop facial recognition algorithms, a large number of faces have to be fed to the algorithm and then labelled as “face” so that the algorithm knows it is a face. If the data that is used to do this is largely white faces, as has historically been the case, then the algorithm performs poorly on other skin tones. Thus, algorithms inherently develop a bias and the more they are used the more they get “trained” to make a mistake unless it is intentionally corrected. The act of identifying previous implicit biases can itself be problematic. How should we respond to the discovery that an accurate model of our current practice identifies a clear practice of bias? How should we treat a colleague who our algorithm has identified to be biased, but whose bias has only been made visible through their voluntary consent to participate in our modelling study?

2.3 Transparency and opacity

How does one know that the algorithm is biased? Detecting algorithmic bias often occurs unintentionally when it demonstrates flawed behavior during actual implementation. Testing algorithms can be challenging since they are essentially "black boxes" kept proprietary by their developers. Additionally, with the rise of deep learning and LLMs, even the creators may lack full awareness of the inner workings and steps involved in generating outputs. The complexity of training neural network-based algorithms makes understanding their functionality nearly impossible. Balancing the need to protect privacy and intellectual property presents difficulties in disclosing algorithmic workings and the underlying training data. This issue is particularly pronounced when dealing with student data, which is regarded as confidential in Europe and often enjoys federal protection in the United States, making it challenging to access the data used to develop a technology. There are several avenues being pursued in this area, especially the subfield of Explainable AI (XAI), where scholars have developed methods to make the use of AI more transparent across the application lifecycle (Dengel, et al., 2021; Doran, et al., 2018).

2.4 Equity and access

ML based technologies for learning can potentially treat all users as equal, ensuring accessibility that is fair to all. They can also things more equitable by prodiving services to those who need it most. Furthermore, they can support scaling up for services at a faster pace than is possible through purely human resources. Given the differences in learning opportunities, prior knowledge, and different backgrounds of students, this is a high barrier for many technologies to meet. For instance, how do you ensure that everyone understands their rights and consents with full knowledge if their technological literacy is different? There are also students that need accommodation due to different reasons and neurodiverse individuals who should also have equal access. Although technology use seems universal, many nuances that need to be worked out to ensure equity in the use of technologies.

2.5 Individual versus community approach to education and learning

Increasing personalisation of services and information may bring economic and individual benefits, but risks creating or furthering divisions and undermining community solidarity. The attractiveness of AI systems is that they can effectively automate the most common tasks; but this risks introducing a “tyranny of the majority”, where the needs of minorities in the long tail are overlooked because they are difficult to automate. The most effective and accurate algorithms, in terms of their predictive power or accuracy, may be based on complex methods (such as deep learning). The inner workings of such algorithms might not be fully transparent to developers and may result in systemic discrimination against a minority class even if it is on average accurate. As argued by Engelbart (1962), complex problems (commonly referred to as "wicked problems" nowadays, such as addressing hunger, containing terrorism, or fostering rapid economic growth) cannot be solved through technology alone (no matter how advanced it may be). The full potential lies in human-computer symbiosis where technologies like generative AI and algorithms are utilied to augment the collaborative efforts of human communities.

2.6 Human-Centered Learning and Human-in-the-Loop Learning

Human learning is not merely a technological challenge. It is important to temper our expectations and recall our past underwhelming experiences with supposedly revolutionary technologies, as emphasised by Langdon Winner (2009). Education is about the humans involved and should remain human-centered. It must also be remembered that education involves attaining proficiency through practice and mastery through understanding, which cannot be automatized automatised or rushed and attained instantaneously. We will do well to benefit from previous systematic thinking on human augmentation so that human capacities and capabilities are effectively augmented to solve the problems humanity face (Johri, 2022).

The operational intention of many ML approaches is that they should be decision support systems, making recommendations to humans who actually make the decisions. Over time, however, there is the risk that this will drift – particularly if the models turn out to be very effective. If a model only rarely turns out false negatives (for instance, failing an assignment it should have passed), for how long will we commit the resources to check all of the negatives for the false one? This question is particularly relevant if false negatives result from implicit bias in our models.

2.7 Speed of innovation versus equality, safety, credibility and sustainability

The rise of AI, and generative AI specifically, has given rise to an influx of funding support for innovation from both the private sector and governments. Across the world, new companies and industries are being formed, leading to new products. Although this innovation is necessary for using AI beneficially, this arms race of sorts is also likely to lead to sustainability and climate change challenges, as well as issues of inequality if this continues to be a winner-takes-all battle. More resources are likely to be put into technologies that will benefit a few as opposed to those with lower profitability but broader impact.

Pursuing technological progress at breakneck speed may compromise the safety, robustness, and reliability of these developments. While adapting to changing times is desirable, universities have historically been slow to evolve. The credibility of universities rests on thorough quality assurance processes, which often struggle to keep up with the latest technological advancements. While an ill-advised response could be to outright ban such technologies, this approach merely introduces enforcement and compliance issues, while further distancing academic practices from the eventual professional practices that are inevitably on the horizon.

2.8 Efficiency vs. effectiveness

AI offers great promise in automating and streamlining the common and recurring aspects of the learning experience. However, in the pursuit of efficiency, we risk neglecting the less common but equally important elements. Although AI is proficient in addressing the majority of learning features, it may encounter difficulties when confronted with exceptional cases and outliers. While we can identify the primary feedback provided by humans to students and create automated systems to deliver it on a large scale, there is a danger of disregarding the valuable feedback that falls outside the common patterns. We must consider how human-machine augmentation can be best practiced so that it does not sacrifice human ingenuity in search for efficiency (Dengel, Devillers, and Schaal, 2021). Having invested in automating this feedback, we may be tempted to reuse the same model in subsequent years without updating it to account for contextual changes, evolving theories, and the distinct learning profiles of each year's student cohort. While there is immense potential for more efficient resource allocation, we must ask ourselves if we can still uphold our graduate standards if we solely focus on automatable outcomes. Moreover, it is essential to consider whether the resources freed up by automation will be redirected to address non-automatable elements in teaching or instead diverted to research, central administration, or budget cuts.

2.9 The dignity of academic work

Technological determinism often dictates that we machines to the extent possible; however, much of higher education has always been experienced, and valued, as an artisanal human process (Crawford, 2009). Increasing automation and quantification could make lives more convenient, but risks undermining those unquantifiable values and skills that constitute human dignity and individuality. This is especially applicable to teaching, which is a personal profession and in most cases a respected profession. The use of technology to automate educational practices risks making the work less dignified devoid of purpose.

3 FRAMEWORKS AND CHECKLISTS

The range of issues highlighted in the previous section motivates systemic approaches to the design and development of AI systems in engineering education. In this section, we will present two existing frameworks, DELICATE and RESPACT, which are relevant for operationalizing AI in engineering education. We then discuss unique challenges posed by generative AI which future frameworks should consider.

3.1 DELICATE

The DELICATE checklist (Drachsler and Greller 2016) was developed as an instrument for educational institutions to engage in ethics and privacy discussions around the use of educational technologies that use Learning Analytics (LA). The authors argue that there are ways to design privacy protections and consent mechanisms so that all stakeholders are benefitted.The checklist consists of the following elements to guide the use of LA applications:

1) ***D****etermination*: Why do you want to apply Learning Analytics;
2) ***E****xplain*: Be open about your intentions and objectives;
3) ***L****egitimate*: Why you are allowed to have the data;
4) ***I****nvolve*: Involve all stakeholders and the data subjects;
5) ***C****onsent*: Make a contract with the data subjects;

6) ***A**nonymise*: Make the individual nonretrievable;
7) ***T**echnical*: Procedures to guarantee privacy; and,
8) ***E**xternal*: If you work with external providers.

Overall, the checklist contains guidance on paying attention to the value of LA and the rights of participants, ensuring that there is transparency about the use of LA and that users give consent openly and willingly. There is also an emphasis on data anonymization and institutional guidance for adopting clear and transparent obligations with any external agencies involved (Drachsler and Greller 2016).

3.2 RESPACT

Another related framework developed on the basis of review of the literature and empirical work (Johri and Hingle, *forthcoming*; Johri and Hingle, 2023) is RESPACT, with applications specifically for educational technologies that use ML/AI and are implemented in an HEI context. The framework consists of the following elements:

1) ***R**esponsive*: The technology needs to be *responsive* to user needs and work *responsibly*. Often the implementation of technologies is done without consideration of whether it fills a need and is usable.
2) ***E**thical*. It is imperative that organizations use some set of *ethical guidelines* for technology procurement and implementation. Institutions may already have access to guidelines for protecting student data that can be expanded for this.
3) ***S**ecure*. The *security* of data is paramount in any technology implementation. With increasing attacks on systems and stolen data becoming common it is vital that insitutions work sincerely towards securing their infrastructure.
4) ***P**rivate*. Privacy is one of the most contentious aspects of technology use and implementation. For educational institutions, it is essential that they view privacy contextually and are guided not just by the law but also by their ethos.
5) ***A**ccountable*. Accountability is another consideration as the misuse of data or of technology has to be righted, and the insitution needs to ensure compliance as well as working within appropriate frameworks.
6) ***C**onsent-Driven*. Consent needs to go beyond simply informed consent to all the involved parties. Consent should extend toward differential schema, so that diverse users can agree to the terms based on their preference.
7) ***T**ransparent*. As technologies get more complex, it is hard for a user to understand all the integrated functions and services and the flow of information or data through the overall system. Transparency is essential for explainability and, consequently, for trust; a user will trust more what they understands better.

Overall, the RESPACT framework, which comes out of empirical work on video-based monitoring of exams (Johri and Hingle, 2023), provides a institutional level set of guidelines for technology use and implementation. While it recognizes that user protection is essential, it also emphasizes institutional imperative of data security and responsiveness to user needs.

Through the exploration of the DELICATE and RESPACT frameworks, we have identified key ethical considerations for the use of AI in engineering education. Both these frameworks stress the importance of transparency, accountability, and the involvement of all stakeholders. They also emphasize the need for consent-driven approaches, addressing privacy concerns, and ensuring the security of data.

3.3 Applicability of these frameworks for Generative AI

While the frameworks listed above are generally applicable to a range of edtech and AI scenarios, generative AI poses some unique challenges, which requires special attention, demanding extension of these frameworks in future work (Kasneci et al., 2023; Weidinger et al., 2021). Some of these new challenges are outlined next:

a) ***Avoiding AI-aided plagiarism***: How to cope with situations where ready-made answers become available to students, who can simply copy-paste them and not disclose such AI-generated plagiarism?
b) ***Avoiding deskilling***: How to cope with deskilling that emerges as students are not required to engage in learning and provided directed answers?
c) ***Enhancement of human capacity***: How can we ensure that the use of generative AI augments human capabilities and does not atrophy them?
d) ***Fair use of AI generated content (AIGC) and AI agents***: Is it ever fair to use AIGC without full disclosure? Is it ethical to leave decision making in the hands of algorithms? Who is liable in case of an inappropriate response?
e) ***Equity and accessibility***: How to ensure that everyone can equitably access the benefits of generative AI and tools do not exacerbate inequality?

Future frameworks should look at the dangers of automation in the field of engineering education and attempt to keep engineering education human-centered and avoid what Brynjolfsson (2022) calls the “Turing Trap” (the focus on automation and artificial intelligence rather than on human intelligence augmentation).

4 CONCLUSIONS

The widespread adoption of generative AI and automation within engineering education raises significant ethical concerns that cannot be ignored. We have highlighted some new unique challenges posed by generative AI such as AI-aided plagiarism, deskilling, the imperative for human augmentation and capacity enhancement, fair use of AI-generated content, and equity and accessibility. These concerns highlight the need for the development of comprehensive ethical AI frameworks that address the unique challenges posed by generative AI. As generative AI technologies become more integrated into education, it is crucial to assess both their short-term benefits and long-term consequences for teaching and learning. The scalability and complexity of these applications require a deliberate effort within the educational community to minimize harm and promote responsible use. Extending existing ethical guidelines to meet new challenges posed by generative AI and emphasizing transparency, accountability, privacy, and human-centeredness, we can mitigate the risks and maximize the positive impact of generative AI in engineering education.

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Exploring the impact of Problem-based learning on student learning outcomes: Findings from the PBL South Asia project

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Conference Key Areas: *Engineering Skills and competences, Lifelong Learning for a more sustainable world, Engagement with Society and Local Communities*
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ABSTRACT

This paper presents the results of surveys conducted among students and teachers / mentors in Nepal, Bhutan, and India, regarding the impact of implementing Problem-based learning (PBL) methodology in engineering and multidisciplinary projects. The surveys were carried out under the Erasmus+ funded project, "Strengthening Problem-based learning in South Asian Universities" (PBL South Asia). The project aimed to address the issues of education quality, employability, and sustainable development in the region by enhancing students' practical experience, communication skills, teamwork abilities, as well as academic knowledge through PBL-adapted courses. As a result, South Asian higher education institutions have implemented PBL courses in their curriculum.

The surveys were designed to evaluate how specific competences or learning outcomes were perceived by different stakeholder groups, e.g., which learning outcomes were expected to be achieved by the faculty, and whether they were achieved by students. Several methods were used for the assessment – open questions with tracking the keywords that the respondents use, as well as "EntreComp" framework which looks into how students assess their abilities to be curious and open, think sustainably, behave ethically, and cope with uncertainty and ambiguity.

Results of the survey showed that student participants have identified teamwork, communication and presentation skills as those most associated with PBL methodology. Among the self-assessed improvement in abilities, students have indicated their increased abilities to assess the needs of different stakeholders, combining different contexts, setting up strategies.

1 INTRODUCTION

1.1 PBL methodology in engineering

The role of practicing engineers in promoting sustainability is vital, as their work is closely tied to societal progress. In recent decades, there has been a growing interest in pedagogical approaches that equip students with the competences required to make effective decisions in a rapidly changing world. These approaches frequently link the United Nations' Sustainable Development Goals with learning outcomes and employ constructivist and student-centered methods to contextualize sustainability issues within local, disciplinary, and professional contexts (UNESCO 2017, Rajabifard et. al. 2021) Problem-based learning (PBL) is one of such approaches that has gained attention as a pedagogical strategy capable of providing the necessary learning outcomes to foster a sustainable society (Thomas 2009).

PBL has been widely adopted in engineering education for its potential in developing students' professional skills, motivation and subsequently, their academic performance (Duch et. al. 2001, Acharya et. al. 2021, Acharya et. al. 2021). By the virtue of this learner-centered approach (Savery 2015), engineering students are given opportunities to actively engage with open-ended challenges (Torp and Sage 2002, Hmelo-Silver 2004) through understanding, finding, learning and applying theories in a self-directed and multidisciplinary way. In terms of professional skills, the PBL approach especially facilitates the development of capabilities needed to work in diverse disciplinary contexts requiring collaborative knowledge construction, which is needed both in engineering professional practice and addressing complex challenges (Torp and Sage 2002, Kolmos and Graaff 2015). These skills are essential for future careers as new and upcoming technologies and tools exceedingly create demand for creative and competent engineers capable of solving complex challenges of the society.

Although PBL has gained recognition as an effective teaching method in engineering education, empirical research on its implementation has predominantly been focused on Western contexts. There has been limited research on PBL in regions where traditional, teacher-centered approaches are still prevalent. Additionally, there are few examples of PBL's practical implementation and effectiveness in cross-institutional contexts, particularly in international collaborations. A study on South Asian universities found that present undergraduate engineering education offered is didactic, content-heavy, lacking adequate practical experience and knowledge of real-world sustainability issues and impact, as well as industry-ready competences (Acharya et. al. 2021). The current undergraduate engineering education scenario – at the regional and local level, through secondary and primary research, highlights the policies and challenges in the face of implementation of the same, due to varied structure of autonomy, as well as resource availability. These are big constraints, especially in South Asian countries with similar institutional contexts such as India, Nepal and Bhutan. The engineering education and curriculum development is usually overseen by the national level body on technical education (e.g. All India Council for Technical Education – AICTE in India; Nepal Engineering Council – NEC). The engineering courses are offered on university campuses or in affiliated colleges. While the independent university campuses enjoy a relatively greater freedom in designing and execution of curriculum for engineering courses (based on broad guidelines from the national bodies), the affiliated colleges are constrained to use the syllabus prescribed by the university to which they are affiliated. Furthermore, the evaluation schemes vary differently between deemed universities. The university-based engineering courses have greater flexibility in assessment schemes, whereas the affiliated colleges are more restricted to follow the guidelines for the universities. The assessment is usually done by a common exam across all affiliated colleges within a university. Thus, the teaching in colleges are geared toward preparing the students for these common examinations, rather than preparing them in solving real-life, 'wicked' problems.

Against this background, this paper reports the impact of a cross-institutional and multidisciplinary PBL methodology on students, teachers and faculty from South Asian and European HEIs.

1.2 Case study: PBL South Asia project

The PBL South Asia project, a joint initiative among ten universities from India, Nepal, Bhutan, Finland, the Netherlands, and Lithuania, was co-funded by the Erasmus+ Programme and led by Aalto University, Finland. The project ran from 15.11.2018 to 14.11.2022 aiming to develop curricula and teaching competence in PBL for global sustainability themes, particularly in the technical field, to enhance critical thinking, innovation capacity, professional skills, and employability among students in intercultural and regional contexts in South Asia. During the project, six partner HEIs from Nepal, India, and Bhutan developed and implemented PBL-based curricula. All HEIs engaged in co-creation of educational content, practices and intercultural engagement around PBL methods application in courses offered to diploma, undergraduate, and graduate students among partner HEIs. The project developed practical teaching competences, transitioning from traditional to student-led learning in the region. It facilitated iterative student-led challenges and interdisciplinary group work, independently and as a component of newly adapted PBL curricula, bridging teacher training in action with peer teaching activities among the consortium members. This approach also encouraged increased engagement between academia and local societal and innovation ecosystem partners to address complex local and global sustainability challenges, while building skills and knowledge among participating students, mentors, and course coordinators.

PBL is no new invention, yet its application in multicultural, multidisciplinary and deeply heterogeneous HEI settings with advanced and beginner levels of PBL adoption is an unusual approach as implemented in the project. It called for a culturally adjusted reinterpretation of normative sustainability agendas, an encounter of entirely different realms of competence, a format in which teachers take the supportive role in facilitation and students take the lead role in learning, balancing and navigating hierarchies and cultural barriers, to develop novel international practices for inclusive PBL education. Project HEIs were organised into three groups: European Programme HEIs, Nepal and Bhutan HEIs aiming for PBL integration and Indian HEIs aiming for best practices development in regional applications of PBL education and teacher training. Activities were mostly based in South Asia, due to the assumption that educational content development needs to take place in the context where it will be rolled out, ensuring actionable changes and locally appropriate modalities. It was also evident that the experienced universities did not have advanced knowledge of teaching circumstances at South Asian HEIs.

Despite serious disruptions to project implementation by the Covid-19 pandemic, the main results and overall impact were achieved. The results include but are not limited to, the introduction of PBL via adapted curricula in Nepal and Bhutan, best practices and teacher training development in India and Europe, a series of international and local student projects, significant institutional engagement and dissemination at consortium HEIs on PBL education, an internationally cocreated MOOC course and modules, follow-up projects and networks.

2 METHODOLOGY

The PBL courses were created or updated in South Asian partner HEIs. Main competences that the new and updated courses are addressing: transversal, behavioural skills, technical, academic, scientific and research skills, linguistic competences, group work skills, interpersonal skills, and learning by doing in the real-world scenario skills.

Before the PBL South Asia project, most of the HEI's in South Asia did not offer PBL courses and most of the teachers/mentors also were not trained in PBL methods. In order to assess the benefits of the PBL questionnaires were designed for students, mentors/teachers, and faculty to be filled in both before and after the PBL courses and distributed online. The surveys were designed to evaluate how specific competences or learning outcomes were perceived by different stakeholder groups, e.g., which learning outcomes were expected to be achieved by the faculty, and whether they were achieved by students. The surveys also investigated PBL practices – the methods used in the courses, the organisation of the teaching/learning process, the logistics, management change, etc. The methodology of questionnaires crosscheck is presented in Fig.1.

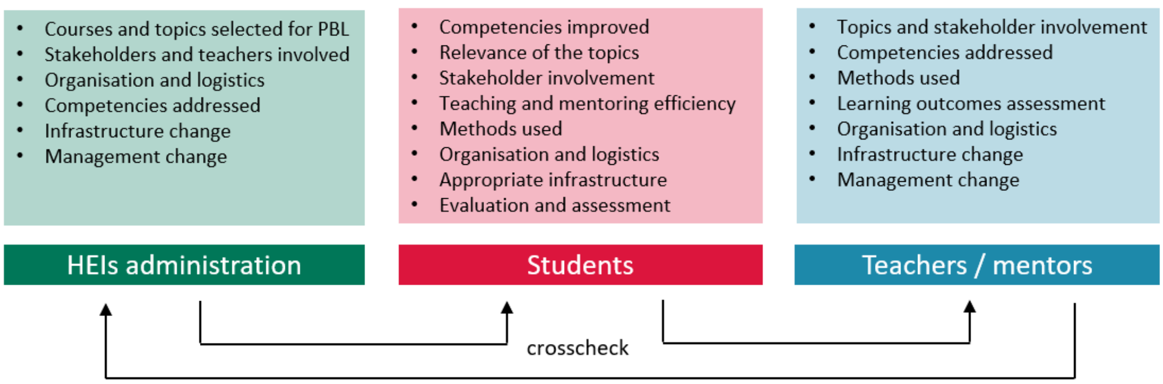

Fig. 1. The PBL SA Methodology of Questionnaires Crosscheck

Two sets of questions were included in the survey – the first set of questions was looking into the overall satisfaction with the PBL courses and understanding of PBL methodology, including the open questions which were used for keyword extraction, as well as collecting the data on the competences increased. The second set of questions was based on the “EntreComp” framework (McCallum et. al. 2020) and investigated behavioural patterns and skills, namely – how students assess their abilities to be curious and open, think sustainably, behave ethically, and cope with uncertainty and ambiguity. The feedback gathered from students’ questionnaires is collected from the updated courses, and thus also reflects the experiences students have had in these various local or international real-life case studies.

A selection of the EntreComp framework was used for the PBL courses evaluation as there is an overlap of competences being addressed in PBL education and entrepreneurship education. The EntreComp framework is a tool designed by a consortium of researchers and funded by the European Union to support the development and understanding of entrepreneurship competences. The framework includes a range of fifteen entrepreneurship-related competences, divided into three main categories: ‘Ideas and Opportunities’, ‘Resources’, and ‘Into Action’. It is designed to be used in entrepreneurship education programs to help students develop their entrepreneurial skills and knowledge.

The first category, Ideas and Opportunities, includes five competences that relate to the identification and evaluation of business ideas. The competences for this category are: Creative thinking, Opportunity identification, Vision, Valuing ideas and taking calculated risks, and Ethical and sustainable thinking. The second category, Resources, includes six competences that relate to the management and utilization of resources to create and run a successful business. These competences are: Mobilizing resources, Financial and economic literacy, Taking the initiative, Planning and management, Coping with uncertainty, and Learning through experience. The third category, Into Action, includes four competences that relate to the implementation of business ideas and the management of a growing enterprise. These competences are: Mobilizing others, Communication and persuasion, Self-awareness and self-efficacy, and Initiative and perseverance.

The total number of students’ responses received before the course was 75. However, approximately 25% of students did not complete the survey after the courses. Nevertheless, this is quite typical in the academic setting, and the participants were only invited to submit their responses twice, in order to avoid random or careless responses just for the sake of responding. The number of mentors who filled in the survey before and after the PBL course was 15 and 14 respectively.

3 RESULTS

Before integrating PBL into South Asian HEIs, questionnaires were given to the administrative staff / managers of South Asian HEIs. The objective was to identify the expectations held by the HEIs regarding the skills and competences that students would enhance through the adoption of PBL. Since only one response per institution was collected for the survey, the detailed findings are not presented in this paper. However, there was a consensus among the respondents, and the expectations of the HEIs revolved around embracing new pedagogical approaches, fostering active learning, producing industry-ready graduates, enhancing problem-solving abilities, improving communication skills, and developing a better understanding of the complex and multidisciplinary aspects of their respective professions.

The results of the students and teachers / mentors responses are presented in Fig. 2.

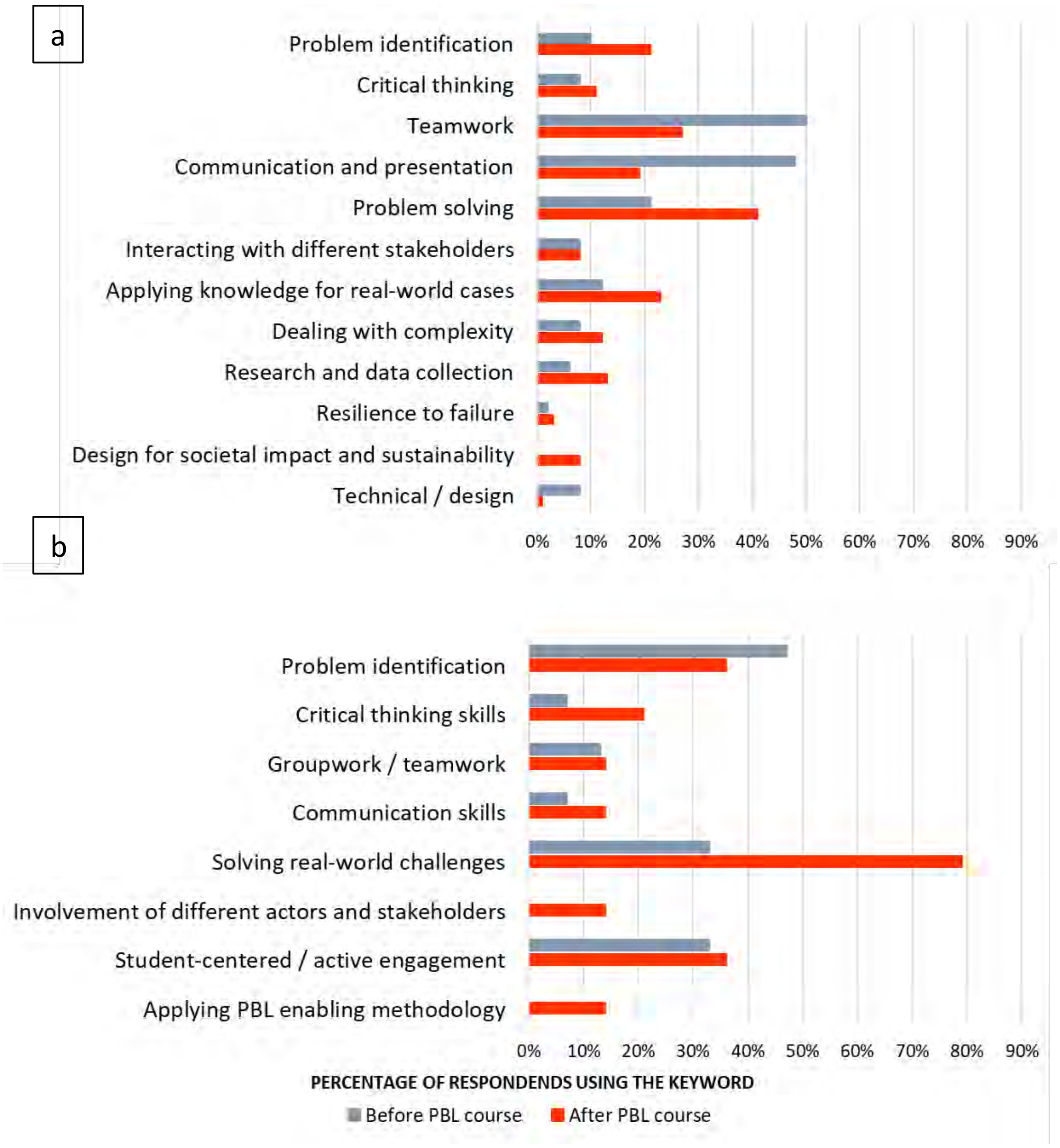

Fig. 2. The appearance of selected keywords in the responses of students (a) and teachers / mentors (b)

The results of the students' responses showed that students perceived the concept of PBL differently before and after the course. As it was mentioned before, open questions were provided for students, where they could write their associations and statements. The chosen keywords indicated how students' perceptions changed before and after the PBL courses. Keywords analysis showed that most of the students extracted these competences obtained after PBL courses: improved technical / design skills; improved teamwork skills; developed skills in communicating with stakeholders; developed communication and presentation skills; built confidence in speaking and listening; improved leadership skills. Keywords analysis also showed that PBL courses had a significant impact on the competences of students.

Analysis of students' responses to the "EntreComp" framework survey showed that students have increased the ability to identify challenges after the PBL courses; they also improved their teamwork skills and their ability to deal with complexity. Keywords analysis and responses to the "EntreComp" framework survey demonstrated that the PBL methodology that was used in the new courses had a positive impact.

Based on the results of the received students' responses, it can be observed that HEIs expectations, which were raised before the PBL courses, have been implemented. Students improved their communication skills along with teamwork and leadership skills. However, it is noteworthy that, after PBL course, students mentioned "Teamwork", "Communication and presentation" keywords less frequently. Instead, they emphasized other aspects of PBL, such as "Problem identification and solving" and "Real-world cases." This indicates that students initially placed more emphasis on the process of PBL prior to undertaking the course, while certain associations became stronger after completing the course, aligning with the outcomes and experiences gained.

A similar analysis was also done with teachers/mentors when the keywords most commonly encountered in their responses were selected, and how their perception changed after PBL courses. Analysis of the appearance of selected keywords in the responses of teachers/mentors showed that the most common keyword appearance was: solving real-world challenges; applying methodology and involvement of different stakeholders; critical thinking skills; communication skills.

The survey showed that courses had a significant impact on the competences in both professional and personal fields. It can be seen that teachers/mentors are able to apply PBL methodology, involve different stakeholders, etc. It shows that after PBL courses teachers and mentors gained the ability to apply new teaching methodologies.

The results of both students' and teachers'/mentors' analysis showed that most of the expectations raised before the PBL courses were achieved.

4 SUMMARY AND ACKNOWLEDGMENTS

Higher education institutions expect new pedagogical approaches and a shift towards active learning to produce industry-ready graduates with advanced problem-solving, communication, and multidisciplinary skills. Students associate PBL courses with improved teamwork, technical, design, communication, and presentation skills. Meanwhile, teachers/mentors emphasize the importance of involving stakeholders, promoting active engagement, and developing real-world problem-solving abilities through appropriate methodologies.

Moreover, the success of PBL integration initiatives relies heavily on continuous teacher support, motivation and networking with other universities in the region. The PBL South Asia project addresses this by creating a PBL network and online course for PBL applications in solving sustainability challenges, which serve as resources for teachers and students alike.

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INTERNATIONAL COOPERATION FRAMEWORK FOR NEXT GENERATION ENGINEERING STUDENTS

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Keywords: *Team-teaching, collaborative, international, experiential learning, University-Business cooperation*

ABSTRACT

International Cooperation Framework for Next Generation Engineering Students (NextGEng) is an Erasmus+ Cooperation partnership in higher education project which started at the beginning of October 2022 and will end at the end of September 2025. In this project, there are six full partners who are participating in all project's activities: Technical University of Cluj Napoca (main partner) and Robert Bosch SRL from Romania; Jamk University of Applied Sciences and Valmet Technologies Oyj from Finland; University of Jaen and Sensory Integration and Robotics from Spain. This project aims to develop an international cooperation framework that promotes international team-teaching aligned with the European Education Area 2025 and labour market needs, including actions to support collaborative, international and experiential learning in engineering. To achieve that end, NextGEng activities are based on three lines of action: a tailored training process for teachers, an international team-teaching pilot program and cases for experiential learning. This paper describes the aims and main activities of NextGEng, details of three lines of action, and achieved results during the first project year.

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1 INTRODUCTION

One of the main objectives of higher education is to provide its graduates with the skills needed to succeed in the labour market. This mission is especially important in the context of today's innovation-driven, skills-based and globalized economies. To produce graduates with strong technical and professional competencies, Higher Education Institutions (HEIs) are facing many challenges. They have to develop new teaching methods that motivate students to learn and become highly qualified graduates with the competencies to work in new kinds of jobs.

Additionally, the last pandemic has meant a sudden transformation in teaching and learning processes, especially in terms of digitalization. Under such circumstances, HEIs have had to adapt their teaching and assessment methodologies in a short time. Transitioning from traditional face-to-face learning pedagogies to virtual ones requires time, expertise, resources, and motivation. The speed with which changes have taken place has affected the learning process and some difficulties have arisen for students to follow lectures or to organize their tasks. Digitalization has fostered the implementation of virtual learning methodologies, which are needed to upgrade the existing materials and to create collaborative work with an international approach (Vincent-Lancrin, S., et al. 2019) and (Visvizi, A., et al. 2018).

New challenges are especially demanding in engineering degrees, where the theoretical complexity and the practical work at the laboratory to train applied skills, require adequate guidance of students from teachers, and the creation of quality learning material. Besides, the industry is one of the most innovative, changing labor agents, and therefore it is crucial to train and prepare future engineers for successful professional development. Based on the above-mentioned, it seems necessary to rethink the teaching methodologies to produce upgraded courses, featuring a student-centered approach and in cooperation with other international institutions and companies. In that sense, the European Commission is working in this direction through the creation of the European Education Area (EEA). Some of the main objectives are related to the improvement of the quality of education from a collaborative perspective, which considers digital transformation and inclusion.

HEI and company partners of the NextGEng project have cooperated for many years, so they know each other's skills and strengths and they have now a good possibility to deepen cooperation. HEI partners have already earlier done successful cooperation and reached good pedagogical outputs and results (Kakko, A. 2016), (Kakko, A., Matilainen, J., Satorres Martínez, S. 2017), (Satorres Martínez, S., et al. 2019), (Torres Jiménez, E., et al. 2019) and (Satorres Martínez, S., et al. 2020). This means that the International Cooperation Framework for Next Generation Engineering Students (NextGEng, www.nextgeng.eu) project is a safe and feasible opportunity to foster the transformation of engineering degrees in line with the aims of the EEA. This project for its part helps to adapt these studies to the changing environment, which demands students to have interdisciplinary, inclusive, cooperative and digital capacities, to quickly adapt to the labor market.

2 BASIC INFORMATION ABOUT THE NEXTGENG PROJECT

This project aims to develop an international cooperation framework that promotes international team-teaching aligned with the European Education Area 2025 and labour market needs, including actions to support collaborative, international and experiential learning in engineering.

2.1 Partners

In the NextGEng project, there are three Higher Education Institutions (HEIs) and three companies from three different European countries (Finland, Romania and Spain) as full partners. *Table 1* shows the countries, names, acronyms and websites of the participating organizations, and also which work packages certain HEI partner leads.

Table 1. Full HEI and company partners of the NextGEng project.

Country	Name	Acronym	Website	Leader of
Romania	Technical University of Cluj-Napoca	TUCN	www.utcluj.ro/en	WP1 and WP3
Romania	Robert Bosch SRL	BOSCH	www.bosch.ro/en/	
Finland	JAMK University of Applied Sciences	JAMK	www.jamk.fi/en/	WP2 and WP6
Finland	Valmet Technologies Oyj	VALMET	www.valmet.com	
Spain	University of Jaen	UJA	https://www.ujaen.es/en	WP4 and WP5
Spain	Sensory Integration and Robotics	ISR	https://isr.es/company/	

The group of partners consisted of two large companies which are well-known around the world and one small and medium-sized enterprise (SME). VALMET is a global, leading supplier of process technologies, automation, and services for pulp, paper, and energy industries. BOSCH is a leading global supplier of technology and services. ISR is a start-up that was born as a spin-off from UJA. ISR has extensive experience in developing new technology solutions and products based on sensory integration and advanced automation for the industry, especially the agro-food sector. Two HEI partners are academic universities while one HEI partner is a university of applied sciences. TUCN is the main partner and coordinator of this project. TUCN has strong academic and research experience, which covers a wide range of engineering and science fields with outstanding results in promoting multidisciplinary and transdisciplinary activities. JAMK is a pioneer of hybrid and virtual education and one forerunner of pedagogical methods in Europe. UJA is one of the most innovative HEIs in Andalusia, Spain, in terms of scientific production and teaching quality, collaborating in initiatives devoted to innovative, virtual methodologies for engineering. The consortium comprises a comprehensive variety of different types of organizations and professionals. This provided very interesting and fruitful cooperation with different perspectives on each aspect of the project. Also, associated companies and institutions and several external partners around Europe follow the progress, utilize the results and perhaps also take part in some of the project activities.

2.2 Work packages

In the NextGEng project, there are six work packages which are Project management (WP1), Tailored training process (WP2), International team-teaching pilot program (WP3), Cases for experiential learning projects (WP4), Quality management (WP5) and Dissemination & exploitation (WP6), as shown in *Fig. 1*.

Three of work packages (WP2, WP3 and WP4) are implementation work packages which are explained in more detail in the following chapters.
The WP1 is led by TUCN and it takes care of overall project management and implementation. The WP1 provides guidelines, communicates with all partners, and periodically evaluates the project's financial situation, ensuring that the activities are implemented on time and according to the project plan. The project managers of full partners and work package leaders form the steering committee. The steering committee has a meeting every six months and during the whole project, only two of its meetings are face-to-face meetings. These two meetings are combined with the annual conference which is named the International Forum of Mechanical and Mechatronics Engineering (IFM^{2}E) and which is hosted by one of the HEI partners in turn.
The WP5 is led by UJA and it provides guidelines for quality assurance, monitors compliance of objectives' evaluation level and it also takes care of risk management.
The WP6 is led by JAMK and it takes care that all promised dissemination and exploitation activities are implemented in time and that the outcomes of different project activities are shared with full and associated partners of the project but also with a large audience.
Most of the meetings and activities of work packages are organized in hybrid and online ways reducing the need for traveling between the partner countries and at the same time reducing negative environmental impact. If travel is necessary for the organized international project activities and meetings, the participants will be informed and guided to choose green travel solutions. All reporting documents of the project are developed in electronic format and stored on the NextGEng MS Team cloud server reducing the need for printing documents.

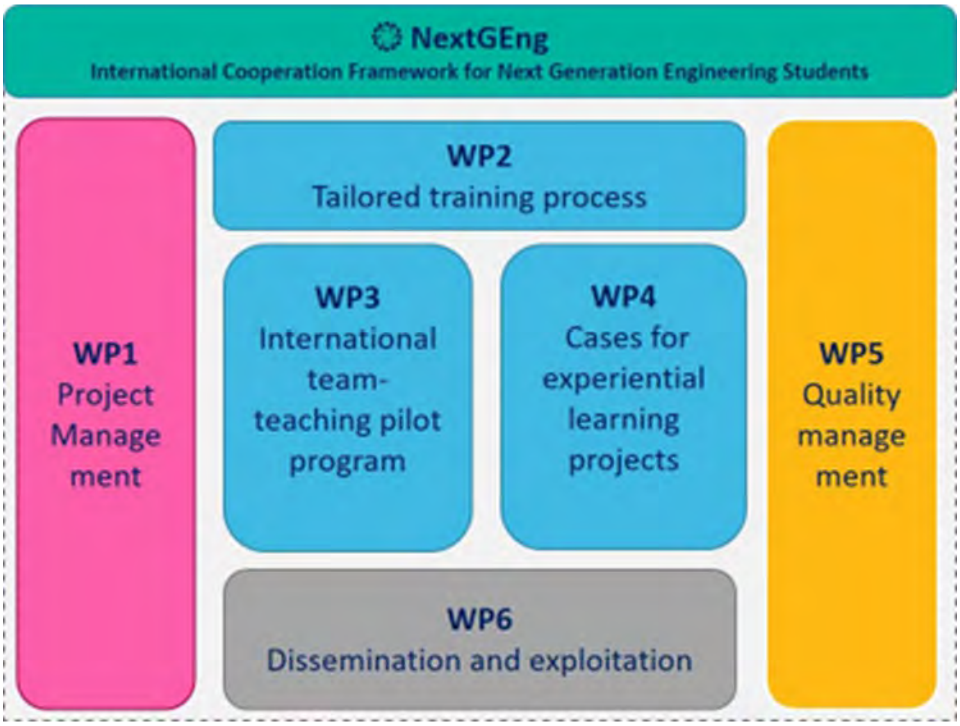

Fig. 1. Six work packages of the NextGEng project.

3 THREE IMPLEMENTATION WORK PACKAGES OF NEXTGENG

3.1 Tailored training process (WP2)

The main content of work package 2 is to design, develop and implement a pedagogical tailored training for the teachers of three HEIs. Experts in pedagogy and teachers with relevant expertise in new cooperative and international team-teaching methods sustain the skill improvement of teachers through workshops and guidance material. During the project, two rounds of tailored training stimulate teachers for innovative learning and teaching practices and the development of an international team-teaching pilot program (WP3). In the NextGEng project, the tailored training is organized by JAMK. JAMK as a forerunner in developing student-centered, competency-based education, digital learning, lifelong learning, and reforming work-related pedagogy and teacher training is the Leader HEI of WP2. The teachers involved in this WP are trained in team-teaching, problem-based learning, flipped learning, and student-centered learning methods. The teachers choose the most suitable methods and their combinations to be implemented in the activities of the following work packages (WP3 and WP4).

The first two-day tailored training seminar was organized at JAMK in January 2023. Many teachers from three HEIs and one expert from VALMET took face-to-face part in it while ISR and BOSCH experts were online. The first training day contained presentations and workshops in small groups. The topics of presentations were student-centeredness, international co-teaching, teaching methods, and digital tools. Also, a general presentation of the NextGEng project was part of the program. In workshops, teachers benchmarked each other’s teaching methods and tools. The second training day started with workshops in six international co-teaching teams. During these workshops, teachers started to plan and design six chosen courses in a student-centered way. They also together settled the next course updating steps after these training days. Next in the program, there were six presentations of the workshops' results. The first intensive and innovative tailored training seminar ended with a summary. The second tailored training seminar will be carried out in the spring of 2024 and will be organized in a hybrid way to reduce the traveling of partners.

3.2 International team-teaching pilot program (WP3)

The aim of work package 3 is to develop a pilot program that implements international team-teaching as a part of the educational process in all three HEIs for the engineering courses in their curricula. The leader HEI of WP3 is TUCN. Six engineering courses of every HEI partner's curriculum have been chosen to be upgraded by applying new teaching methods and updating existing content in close collaboration with company partners. The selected six joint courses contain both fundamental and advanced ones, and they are Strengths of Materials (C1), Industrial Automation (C2), Design Project (C3), Quality Assurance and Applied Methods (C4), Computer-Aided Design (C5), Manufacturing Technologies (C6). For each course, an international co-teaching team was formed that includes teachers from all three HEIs and company experts working together to develop new teaching materials and teaching methods. The first face-to-face meetings of co-teaching teams were at the first tailored training seminar at JAMK in January 2023. During the first project year (10/2022-9/2023), the upgrading process started with four courses (C1, C2, C3 and C4) and two other courses (C5 and C6) will be added to the process in the second project year (10/2023-9/2024). During the second project year, cooperative teaching implementation of four upgraded courses will be implemented as a part of the

teaching semesters in all three HEIs. During the third project year (10/2024-9/2025), cooperative teaching implementation of all six upgraded courses will be implemented as a part of the teaching semesters in all three HEIs.
The course upgrade process supports the development of new course materials in electronic form that is shared using online platforms with the enrolled students and presented to students during hybrid team-teaching sessions in which teachers and students participate face-to-face and online. After these two teaching rounds, the learning results will be evaluated and compared with the students that have followed the standard course program. During the third project year, the best practice guide for international team-teaching in engineering will be created and it will be published as a result of WP3 at the end of the project.

3.2 Cases for experiential learning projects (WP4)

The aim of work package 4 is to design, develop and implement two rounds of new student semester projects called Cases for experiential learning (CEL) projects where international student groups are involved in solving research or an industry-specific topic in direct collaborations with HEI teachers and company experts. The leader HEI of WP4 is UJA. The design of the CEL projects is shown in *Fig. 2*. In both CEL rounds, three projects will be simultaneously implemented, one in each partner HEI and country. In every project, six students from every HEI will take part in, so together 18 students. In every project, there will be formed three international teams of six students that will solve the same topic and compete against each other to create the best solutions for the proposed challenge.

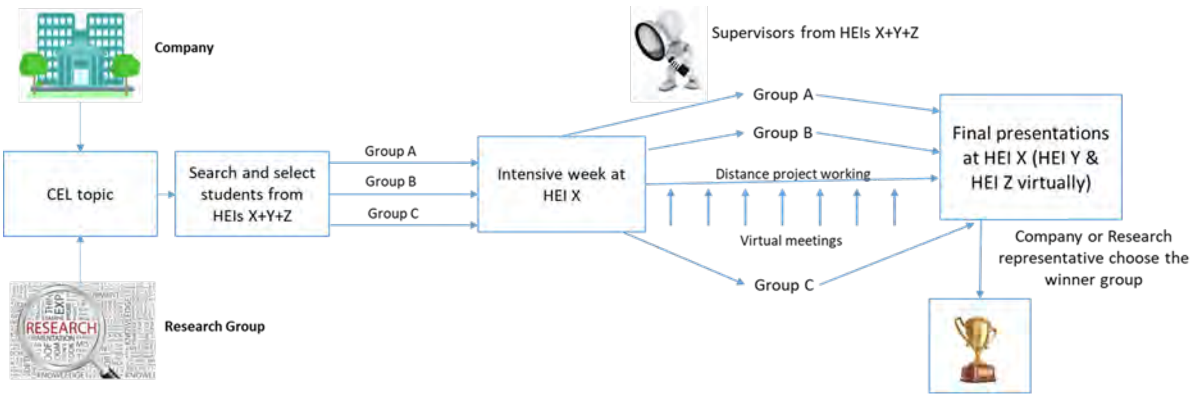

Figure 2. The design of CEL projects.

In the spring and summer of 2023, HEI teachers and company experts in three partner countries have together chosen the most suitable topics for three CEL projects. During autumn 2023, HEI and company partners will create info materials and write detailed plans for the first round of CEL projects. They also have info sessions for suitable student groups in their HEIs. After that, interested students will send their CVs to the teachers of their own HEI who will choose six students for all CEL projects. The first round of CEL projects will be implemented in the spring and summer of 2024 and the second round in the spring and summer of 2025.

At the beginning of every CEL project, there will be an intensive week in the HEI and the company where the topic will come from. All students, HEI teachers and company experts who will take part in a certain CEL project will participate in this intensive week. The student program during the intensive week will include tailored lectures, group work, group presentations, supervision meetings with teachers and company experts, and also some free time activities. After the intensive week, the student groups will continue solving the project topic remotely. The groups will regularly hold their own remote meetings where they will discuss the progress of the project and share outputs. Student groups will also have virtual meetings with teachers and company experts. At the end of every CEL project, there will be oral final presentations of student groups which will be organized in hybrid. Student groups also will write their final project reports. Teachers and company experts will evaluate the work of the student groups, choose the winning group and give grades to them.

4 SUMMARY AND ACKNOWLEDGMENTS

The three-year NextGEng project started at the beginning of October 2022. During the first project year, HEI and company partners have done all scheduled activities with a good attitude and on time. Cooperation between HEIs and companies has been innovative and fruitful. All participating organizations can learn new and useful things from each other and from this project.

The Tailored training process (WP2) is the first implementation work package whose activities will end and be ready in spring 2024. The most suitable methods and their combinations learned in WP2 are tested and implemented in two rounds of the International team-teaching pilot program (WP3) and in two rounds of the Cases for experiential learning projects (WP4) during the two last project years. During the academic year 2023-2024, cooperative teaching implementation of four upgraded courses and the first round of experimental learning projects are implemented as a part of the teaching semesters in all three HEIs.

The NextGEng project implements green practices at individual, institutional, and project levels. The aim is to reduce the environmental negative impact by reducing and optimizing the necessary travel activities, using digital tools for document management, raising awareness, and developing new green competencies for the target groups in the project. If travel is necessary for the organized international project activities and meetings, the participants will be informed and guided to choose green travel solutions that reduce as much as possible the carbon footprint of this mobility.

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SHARED INTERESTS IN LIVE CASE-BASED LEARNING – STUDENTS' DYNAMIC ROLE IN AN INNOVATION ECOSYSTEM

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ABSTRACT

Teaching engineering students to navigate complex innovation ecosystems and deal with wicked problems is vital for contributing to sustainable development. Research shows that case-based learning with real-life challenges boosts motivation and learning outcomes. This paper presents a course that is in the core of an ecosystem where engineering students engage with hospitals, and work on the hospitals' documented innovation needs. By design, the course setup has a double purpose: in a learning context, the course strengthens intrapreneurship education, with students acting in an empowered role like professional consultants. In an organizational context, the course enhances knowledge sharing, filling in the gap of innovation competences and resources needed to create value and stimulate intrapreneurial initiatives. The ecosystem has evolved as result of an iterated development of the course including the tools and frameworks that empower the students to act as autonomous innovation consultants in constant interaction with the process of mobilizing the case partners. Thus, this paper presents a study based on current experiences and learnings, focusing on the relationship between the facilitation of student empowerment in live case-based learning and the impact on both 1) engineering students' motivation and learning outcomes; 2) value creation for the participating ecosystem. The paper builds on qualitative data from two sources: yearly follow-up interviews with case partners since 2018, and student reflection reports from 2022.

1. INTRODUCTION

After hosting a group of engineering students from an innovation course in the department, a senior consultant physician in a palliative care unit at a Danish hospital said that:

"[The students] have been super observant. It is wonderful to have eyes from the outside on such a messy shop as ours. They see some of the same things that I see, but they can say it impartially. It has been extremely useful."

Students wrote in a reflection report after another project at the same course:

"The doctor confirmed the skills we had learnt and were now using on the ward. It left us with a great feeling. We already felt we had made a difference by proposing concrete places to look to solve some significant problems. It was a much better feeling than getting an A grade."

These initial quotes remind us that the education of engineering students has become more than just teaching the technicalities of the engineering profession. Engineers nowadays are often placed in interdisciplinary contexts, where they work with complex problems, or so-called 'wicked problems' (Buchanan 1992). Moreover, it is often the case that the complexity increases when involving multiple stakeholders in intricate organizational webs. To prepare engineering students to their future professional reality, higher education institutions create and modify courses to expose students to real-case scenarios, interdisciplinary group work, and collaboration with organizational partners.

One example of an engineering program that aims to empower students to work in highly complex organizational environments is the bachelor study program of Process & Innovation, at Technical University of Denmark. The Process & Innovation study program educates design engineers. The students become generalists, and as it is written in the introduction at the university's website: "As an innovation engineer, you can help translate new ideas into concrete and usable solutions" ("Bachelor of Engineering (BEng) in Process & Innovation" 2023). The students "learn to work professionally with innovation and the implementation of new concepts, products, and processes from an engineering perspective" (ibid).

Early in the Process & Innovation study program, students are exposed to wicked problems, but the 4th semester course, entitled 'Innovation in an Organizational Context' (IOC), is their debut with live case-based learning in a professional context. Specifically, students in the IOC course work with hospital wards for 20 weeks.

The IOC course objectives aim:

"To enable the students to clarify, problematize and constructive relate to the relationship between organizational culture, knowledge dynamics, organizational changes and value creation, and the underlying socio-technological innovation ecosystem, and on that basis in praxis facilitate innovation in an innovation ecosystem" ("Innovation in an Organizational Context. Course Description" 2023).

In this practice paper, we frame the IOC as a case on how to facilitate student being part of an innovation complex organizational ecosystem. As outset, we consider that there are two main actors interplaying: the students and the professionals at the partner organization. Students act with an empowered role as professional consultants in the organizational ecosystem, whereas professionals act as contact points, i.e., sources of knowledge for students to explore the system and receivers of the finalized student project and derived value creation. These two actors have shared but also distinct expectations to be aligned.

Based on that, we investigate and discuss the following:

How does the expected value creation that meet the students in the organizational context in the ecosystem influence their motivation, learning outcome and self-efficacy?

We outline the course structure, the applied learning elements, and the process of mobilizing the ecosystem with support of empirical data.

2. METHODOLOGY

The paper builds on qualitative data from two sources:

- Follow-up interviews with case partners (hospital wards).
- Submitted student reflection reports.

Since 2018, 24 hospital wards have participated as case partners. In the same period 35 semi-structured follow-up interviews have been conducted. Typically, the respondents were the head of department and/ or the case contact person and, eventually, other staff members. The interviews have, with minor modification, followed an interview-guide, where questions were asked in four categories:

- The cooperation between students and the ward in general.
- The delivered outcome in the specific case.
- The perceived value creation.
- The effect of the students' presence in the department's work life.

The interviews have been recorded and transcribed. In the reflection reports, students ought to reflect on key events, on collaboration with the department, and on the group process applying Gibb's reflective cycle (Graham Gibbs 1988).

Both categories of data have been coded following a code list, including the terms 'value creation', 'trust', 'relations', 'process', 'expectations', 'optimism', 'motivation', 'feedback', 'engagement', 'ownership', 'efficacy' and more. In total, the analysis builds on 10 reflection reports and 35 follow up interviews from the period 2018 to 2022. Additionally, the paper also refers to course description and internal materials.

3. THEORETICAL BACKGROUND

3.1 Self-efficacy in live case-based learning

Case-based learning is an instructional approach broadly implemented in university education of nursing, medicine, law and business education, but that is still at its infancy in engineering education (Maslen and Hayes 2020). Case-based learning exposes students to cases, i.e., specific situations, scenarios, or problems that resemble real-world challenges they will encounter in their professional practice (Tripathy 2008). On way of implementing case-based learning is through live cases, where students are placed within an organizational context interacting with other key actors (Blomkvist and Uppvall 2012).

The practice of live case-based learning encompasses the idea of students perceiving themselves as being responsible for an outcome, while still having the support of their group mates and the facilitation of the supervisor. Tinto (2017) positions 'self-efficacy' as one of the key elements in the model of students' motivation and persistence in their education, together with 'sense of belonging' and 'perception of curriculum'. *"Self-efficacy is learned, not inherited"* (Tinto 2017), meaning students build their sense of self-efficacy from the experience with others and the situations in which they interact.

In this paper, we depart from the assumption that live case-based learning can potentially increase or decrease students' sense of self-efficacy, as they move along to work on their cases. Whilst a real case seems very challenging, students might increase self-efficacy if they find ways to navigate complexity, so that even difficulties on the way do not stop them to persist. We understand self-efficacy as a core element needed to be strengthened through practice of engineering education.

3.2 Value Creation in live case-based learning

In the last 20 years, universities have grown more entrepreneurial and have undertaken different forms of innovation collaboration with companies, comprising, for instance, students' live case-based learning (Perkmann and Walsh 2007). Live case-based learning has developed particularly important to partners who are new to innovation processes or that do not have enough dynamic capabilities to cope with innovation, such small enterprises, non-governmental organizations, and institutions like hospitals (de Silva and Wright 2019). Societal actors engaging with students can benefit from a multitude of advantages, such as access to skilled workforce, corporate societal responsibility efforts, ecosystem orchestration etc., while having a first evaluation of the efforts and outcomes of interacting with universities (Rafaela Hillerbrand and Werker 2019). Then, live case-based learning courses work as a platform that connect various actors to students and create reciprocal and shared value (Osorno-Hinojosa, Koria, and Ramírez-Vázquez 2022).

Nevertheless, as each collaboration is different and it involves actors with peculiar necessities, universities often struggle to balance out value creation for both the students and the interested stakeholder(s), but also value capture for itself (McAdam, Miller, and McAdam 2018).The difficulty comes from the nature of such shared value creation because value creation is both individually perceived and experienced (Lusch and Vargo 2006), and it is influenced by the different ecosystem in which each actor is contextually embedded (Jennifer D Chandler and Lusch 2015).

The case presented in this paper involves hospital wards, who revolve around their complex own ecosystem, multiple customers, and value creation strategy ("Budgetaftale 'Tid Til Patienten'" 2020), and students with separate logics. Therefore, while value creation is the objective of students' collaborations as a strategic capability that might drive actors' engagement and further the university ecosystem development (Orazbayeva et al. 2019), it also evolves along the interaction's deployment, as it is defined, discovered and evaluated, in intertwined feedback loops (Polese, Ciasullo, and Montera 2021).

4. THE IOC ECOSYSTEM

4.1 Course origins and design

The IOC course originates in the merge of two other courses: 'Innovation and Knowledge Management' (IKM), a 5-credit course lecturing an organizational curriculum, and 'Project 4' (P4), a 10-credit project course. Over the years, the two courses (IVL and P4) have gradually been integrated and continuously developed, as well as a network of partnerships was established, until they became integrated as IOC. The IOC course ran for the first time in Spring 2023 as a 15 credit, 20-week project-based course, where groups of students work with hospital wards as cases, one case per group.

The IOC course design uses 'active learning' and 'flipped classroom' as its key teaching methods. Students work in groups and need to apply the syllabus in practice ('active learning'). Each group is responsible for managing the workload from the course, which includes three mandatory deliverables, and one final implementation plan together with an 'innovation log' that documents needs and opportunities discovered through the process to the hospital department they are working with. To support their work, students are exposed to organizational theory, with literature available and have peer feedback sessions ('flipped classroom'). Moreover, there are several informal knowledge-sharing sessions in the class.

4.2 Hospital wards as cases

The first healthcare case was introduced in 2016, before IOC was created. The hospitals soon proved to be the ideal arena for learning innovation, as it says in one of the course guides:

"A hospital ward is a complex organization where changes constantly are taking place in a bubbling cauldron of citizens with needs and feelings, their relatives, professionals, and specialists from many fields who work together and are interdependent. It is a hierarchical organization influenced by political interests, financial requirements, and intense technological development" (Keiding 2023).

In 2018, it was decided to focus entirely on healthcare cases. Gradually, as a network of case partners has evolved, the course established itself as an actor in the innovation ecology in the hospitals.

4.3 The story about the course

The systematic documentation of the departments' experiences by follow-up interviews has played an important role in establishing the course as an actor in the ecosystem. A narrative has formed around the course, built from statements extracted from the interviews. Currently, value creation has become the selling point of the course for the hospital wards. This extract of the invitation letter to new wards exemplifies the emphasis on value creation:

“You have a busy life and there are probably several things you would do if you had the time. Why not let a team of engineering students do the work? You don't need to spend time formulating a case because that's the students' job. They must […] create the most value for employees and patients” (Keiding 2023).

5. EXPLORATION AND DISCUSSION

In this section, we explore the empirical data and discuss the topics introduced earlier. We use extracts from the data (i.e., quotes from student reports and follow-up interviews) to exemplify and illustrate key aspects identified.

5.1 Response from the real world

The learning outcomes from the students are closely linked to the response from the hospital partners, as exemplified in one student report from Spring 2022:

"Just as the department benefits from our new eyes on their work, we must also value their view at our work and recognize that it is not us and our high expectations to our own work that determine whether we make a difference for others, but it is actually them for whom we create value” (Group 8, 2022).

Here, the group let go of a self-centred approach to learning, shifting to a real-life focused approach, acknowledging that the project should be guided by the value creation perceived by the partner.

The value of having *“new eyes on their work”* is often apprised in the follow-up interviews, which demonstrates the individually perceived and experienced perspective on value in the case-collaboration (Lusch and Vargo 2006):

"We become blind to our own practice, so having our eyes opened by someone who comes from the outside and is not immersed in all sorts of things is insanely good” (Group 8, 2022).

The significance of the foreign glance seemed to be mutual since *“their view at our work”* is claimed by the students to be a central motivational factor, obviously more important than ”our high expectations to our own work”, a figure of speech that presumably refers to normative project assessment. What determines the quality of the project from the perspective of the students is *“to make a difference”* and to *“create value for [the hospital partner]”*:

“We must therefore become better at taking in the praise but also seek their validation, as it helped to create peace and confidence in our work. Specifically, we want to strengthen the contact with our stakeholders in the further work, to gain a deeper insight into their perception of our work” (Group 8, 2022).

It is a learning outcome to actively aim for a close interaction with the real world.

5.2 Accomplishing a value creating role in the ecosystem

Some student groups experienced to be seen as a resource in the hospital wards. A group took part in an ongoing project about home monitoring of heart patients:

"Through this process, we have gone from being observers to being key players in helping the department to further develop the use of Apple Watches. It has been enormously rewarding and motivating that [the hospital contact person] appreciates our labour and believes in our work. It has energized us and pushed us to be careful and thorough in our work" (Group 9, 2022).

The group accomplished a valuable role in the ecosystem. Their conclusion indicates a strengthened self-esteem:

"Our delivery from this course will be one of the cornerstones in the future maturation and implementation of the system" (Group 9, 2022).

5.3 Self-efficacy and the mobilization of the ecosystem

It is an important learning for students that successful value creation is not only determined by individual skills and a good solution, but by the ability to adapt to the ecosystem. Some actors demand hard work to mobilize.

In the following example, doctors and a senior consultant physician were the key actors, but the group had only been able to access the physicians through the ward nurse. The project took a major step forward when the senior consultant physician finally became interested in the project. All began at a meeting with the ward nurse:

"The meeting boosted morale within the group and increased motivation for future work. Prior to the meeting, it had been unclear whether the proposed solution had real value for the ward and we ourselves had begun to doubt its relevance. The ward nurse had a drive and enthusiasm that was contagious. She encouraged us to just go out and try the solution and gave full support to the project" (Group 11, 2022).

The ward nurse had no doubt that the group could win the staff for the proposed solution. Energized by positive expectations, they approached the physician:

"We were very motivated to continue the work and test the prototype because we felt that we had mobilized the key person [the ward nurse] for the implementation of the solution […] However, we ran into a problem when the situation did not allow us to just walk into a doctor's consulting room and demanded that they tested the prototype without the ward nurse present […]" (ibid).

The group conducted a workshop to create a *"direct link"* to the doctors. During the workshop, it became clear, that the doctors did not share the positive expectations of the ward nurse. A turning point occurred while an interaction played out:

"[…] when asked about whether the information about the waiting time can be registered and viewed in the Health Platform (SP), the consultant physician and another doctor shared knowledge. The consultant physician realized that the other doctor has been using the Health Platform differently, with the effect that the current delay in relation to the schedule was visible to the entire staff" (ibid).

The debated feature was of value to the doctors since the registration happens automatically and reduces interruptions.

“The consultant physician ended up asking the facilitator [one of the students] whether the proposed solution would be a technical possibility” (ibid).

The workshop did not establish the wished *“direct link”*, but it made the students of use to the doctors. The situation led to an important learning:

“The idea of having to facilitate a person who has the daily leadership role was very challenging and made it difficult to stick to the framework and purpose of the workshop. […] However, the workshop resulted in great joy as the doctors started to share work process experiences internally. This is where the effect of the workshop really came into play, and it was a feeling of success to have "overcome" the participants who probably represent the most difficult to mobilize” (ibid).

This is a case of confirmation of the professional capability of the group. The doctors did not directly praise their proposal, but a change in perception occurred and confirmed the process, and thereby the professional capability of the group to manage that. *“This is where self-efficacy is learned”* with the words of Tinto (2017).

6. CONCLUDING REMARKS

6.1 The ecosystem evolves

In general, there is a positive dynamic in the ecosystem, pumped by a high degree of expectations from both case partners (i.e., hospital staff) and students. Hospital staff warmly welcomes the new students with expectations that they will create value and produce good results as their past cohorts. Students, on the other hand, are motivated to make the efforts to these meet expectations. In most cases, they succeed and add to their professional ethos and self-efficacy.

Later in the study program, some students continue with their projects or other projects in the healthcare sector and become role models to the new students. At the hospitals, among the healthcare departments, the word about the IOC course and the results are spread when managers bring the results to various forums and when staff move to new positions elsewhere in the sector.

6.2 Final notes

This practice paper takes the ecosystem perspective on value creation and uses the example from the IOC course to explore the interconnectedness between students’ motivation, self-efficacy, and learning outcomes, and the value creation for the case partners.

With this paper, we do not present a simple answer to the question raised, but a – still hypothetical – model seems to emerge. The learning dynamic plays out in a multi-connected feedback loop formed around 4 key concepts:

- Value creation in one year leads to positive expectations from the hospital wards towards the students in the next year.
- Positive expectations are expressed in a welcoming attitude from hospital staff and leads to strong student motivation.
- The students benefit from the strong motivation in the form of enhanced self-efficacy and learning outcomes.
- Enhanced learning outcome goes together with improved value creation for the wards.

The model is expanding as the ecosystem is mobilized, both by the students as a mean for them to learn and in the process of recruiting more department as cases. In the end, to the students, the dynamic seems to be able to provide a lot more *“than getting an A grade”* in terms of self-efficacy and motivation.

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SUSTAINABLE ENERGY-EFFICIENT LIVING – A FIRST-YEAR PROJECT-BASED WORKSHOP FOR ENERGY ENGINEERS

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ABSTRACT

For many engineering students a lack of study motivation plays a significant role in their drop-out process (Heublein 2014). Therefore, students' motivation to study should be encouraged as early as possible. A proven strategy for increasing the study motivation is the integration of project-based learning (PjBL) in the course of studies (Kokotsaki et al. 2016).

This paper introduces a PjBL-workshop concept which was developed for first-year energy engineering students at a university of applied sciences in Germany. During

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this one-semester workshop, the students are working weekly as student trainees in a fictitious engineering office. Guided by the teacher as the project lead, the students are developing a concept for integrating various renewable and sustainable energy systems in a single-family home. Each week they take on subtasks of a different work package supporting other employees of the engineering office. During their time as student trainees they have to face authentic engineering challenges like constructing a photovoltaic plant or dimensioning a battery system. Progress and results are documented in a project journal.

First insights of initial implementations of the concept led to a closer focus on the aspect of the perceived authenticity of the PjBL-setting (engineering office) by the students. Therefore, besides the conceptual and contentual design of the workshop, this paper will also address the creation of the authentic setup of the engineering office.

Future research in this ongoing study will examine the influence of the perceived authenticity on various aspects such as the motivation to study.

1 INTRODUCTION

The demand for well-trained engineers has never been higher. However, institutions of higher education are still struggling with increasing dropout rates in engineering study programs. As a main reason for their dropout in the first semesters many students state a lack of motivation to study (Heublein 2014).

One strategy to counteract these dropout rates can be the integration of the student-centred (Kokotsaki et al. 2016) approach of project-based learning (PjBL). This method is widely used in engineering education (Chen et al. 2020), provably increases the students' motivation to study and provides many benefits and engineering skills for students, like enhanced critical thinking, independent learning (Frank et al. 2003) and improved problem-solving skills (Harmer and Stokes 2014).

In order to promote the study motivation as early as possible, PjBL should be used from the beginning of the study program. In this paper, a PjBL-based workshop for first-year energy engineers will be introduced. Therefore, the challenges of the PjBL implementation, the framework and the structure of the workshop-concept will be described. An overview of the content design of the workshop will be presented afterwards. In addition to the conceptual and content design, this paper will also focus on the design of the authentic setting. Finally, an outlook on the next steps in this ongoing study is provided.

2 PROJECT-BASED LEARNING

Defining PjBL is challenging due to different understandings of the term in different countries and disciplines (Harmer and Stokes 2014). Sometimes it is used similarly or interchangeably with problem-based learning (PBL) (Harmer and Stokes 2014). Differences and similarities between these two approaches will thus be discussed later in this paper.

PjBL can be considered as a particular type of inquiry-based learning (Kokotsaki et al. 2016), as many elements of PjBL are derived from this method (Frank et al. 2003). Inquiry-based learning itself is based on the constructivist teaching approach, according to which students learn concepts or construct meaning through their interaction with others and their world (Frank et al. 2003). Therefore, three constructivist principles are forming the fundament for PjBL (Kokotsaki et al. 2016): (1) learning is context-specific, (2) learners are involved actively in the learning-process and (3) learners achieve goals through social interaction and sharing of knowledge and understanding. From these principles, seven main characteristics of PjBL can be deduced.

2.1 Main characteristics

In accordance with principle 1, the context of learning for PjBL is provided through *authentic driving questions* within real-world problems (Kokotsaki et al. 2016), which form the fundamental element of the project. These complex and open-ended problems are often identified by the teacher and further developed by the students during their investigations (Harmer and Stokes 2014). Essential for the approach is, that the outcomes or solutions for the problems are not predetermined, so that the students have a flexibility in their problem-solving process (Harmer and Stokes 2014).

During their investigations the students are involved actively in the learning process (principle 2) (Kokotsaki et al. 2016). Active here means *learning by doing*. The students' role changes from the traditional, passive listener to an active maker (Harmer and Stokes 2014). Hands-on experience in practical projects strengthens the connection and identification with the faculty and gives an informed view of the target profession (Harmer and Stokes 2014).

To take more responsibility for their own learning, the projects are mainly student-driven (Kokotsaki et al. 2016). With a high degree of *autonomy*, the approach leaves space for developing own methods and procedures (Harmer and Stokes 2014).

Whereas student independence increases, the teacher moves more into the background and acts as a facilitator or a mentor during the project (Kokotsaki et al. 2016, Frank et al. 2003, Harmer and Stokes 2014). As often found in the literature the shift of the teachers' role can be described as from a 'sage-on-the-stage' to a *'guide-on-the-side'* (Harmer and Stokes 2014). The teachers' task is to create a contextualised learning environment, that allows students to construct their own knowledge (Frank et al. 2003), while balancing their need for support and autonomy (Harmer and Stokes 2014).

The third principle indicates the need for social interaction and collaboration in the learning process (Kokotsaki et al. 2016). PjBL is based on *team work* where students learn important skills like interacting, communicating and planning as a preparation for their future everyday engineering life (Harmer and Stokes 2014).

PjBL-projects often either cross or combine multiple disciplines (Harmer and Stokes 2014). *Interdisciplinarity* enables a differentiated view of the boundaries of one's own discipline and the points of connection with other disciplines.

One of the most distinguishing features of PjBL is the creation of an *end product*, which drives the whole process of planning and realisation of the project (Harmer and Stokes 2014). The types of outputs or artefacts vary from real products (Frank et al. 2003) to presentations and reports (Kokotsaki et al. 2016). The end products are usually shared with an authentic and appropriate audience, like fellow students or teaching staff (Harmer and Stokes 2014).

2.2 PjBL vs. PBL

The construction of an end product or concrete artefact is not only the most signifying element of the PjBL approach, it is at the same time the feature that distinguishes it the most from the related PBL approach (Kokotsaki et al. 2016).

Both approaches are based on similar principles with focus on problems with relevance to the real world. The two of them are working with collaboration of the students (Kokotsaki et al. 2016) and facilitating teachers. The main difference between them is, that PBL primarily concentrates on the process of learning (Kokotsaki et al. 2016) or producing a plan or a strategy (Harmer and Stokes 2014), while PjBL focusses on the creation of a real end product (Kokotsaki et al. 2016) or carrying out a plan (Harmer and Stokes 2014). The challenge is furthermore, that these two terms are sometimes used equally, distinguished or combined, depending on the discipline, the country or the regarded research group (Kokotsaki et al. 2016). In this paper, these two approaches are considered as similar but distinct.

2.3 Challenges

Implementing PjBL with all its elements is challenging. In the literature, a wide range of challenges is reported. Chen et al. (Chen et al. 2020) identified several challenges on individual, institutional and cultural level for students and teachers, the most on the individual level. For the teachers, a lack of training as facilitators and the choice of assessment is the main challenge. For the students, it is the lack of teamwork skills, self-learning skills and project management skills that causes problems (Chen et al. 2020). Harmer and Stokes (Harmer and Stokes 2014) and Kokotsaki et al. (Kokotsaki et al. 2016) each present a set of recommendations to master these challenges.

2.4 Authenticity in PjBL

Furthermore, Strobel et al. (Strobel et al. 2013) address a concern regarding the design of authentic learning environments, like in the PjBL approach. ‘What is considered authentic to the teacher is not necessarily authentic to the student’ (Strobel et al. 2013, p. 144). In addition to that, the term authenticity is ‘often used without reflection or clear definition’ (Strobel et al. 2013, p. 144).

According to Bialystok (Bialystok 2017), in order for something to be perceived as authentic by the students, it does not have to correspond to the actual reality, but to what students assume to be their personal reality. Therefore, it will be important and necessary to know the students' personal reality regarding the project scenario or the project environment in order to be able to provide them with an authentic experience during the project.

3 PROJECT-BASED WORKSHOP

The following chapter introduces a workshop designed according to the characteristics of PjBL presented in section 2.1. First, the framework conditions for the workshop are explained, afterwards the implementation of the PjBL elements is described in detail.

3.1 Framework conditions

The PjBL-workshop is part of a mandatory first-semester introductory course for freshmen of two energy engineering study programs at a university of applied sciences in Germany. The study programs share basic courses and specialise towards energy systems or energy information technology. The course consists of a lecture (3 hours per week) and the weekly practical PjBL-workshop (2 hours per week) and has 6 ECTS. The semester lasts 15 weeks, whereby 2 weeks are provided as self-study weeks and are thus omitted as lecture weeks. The grade for the course is composed of 70% of the assessment of the lecture and 30% of the workshop, what will be described in detail in the next section. The lecture will not be discussed further in this paper.

During the winter semester 2020/2021 the workshop was performed as a reduced online version due to the pandemic situation. The course started with 40 active participants and finished with 35. In the winter semester 2021/2022 the workshop could be carried out in presence in its intended version. At the beginning of the semester, the number of participants was 34 students, which dropped to 25 by the end of the semester. The reason for dropping out of the course was mainly due to dropping out of the entire degree programme or changing the degree programme. The attendants of both years were mainly first-year students, a small amount was from higher semesters.

3.2 Implementation of PjBL

The story for the authentic scenario in this PjBL-workshop begins with a young couple, who bought an old single-family home from the 1960s. They hire an engineering office to develop a concept for the integration of renewable and sustainable energy systems to their new house, as they want it to be fully renovated and modernised. Working as freshmen student trainees in the engineering office, the students are involved in this new project. By taking on subtasks of different work packages every week, they support other employees of the fictitious office.

The described authentic driving question of this project is identified by the teacher, who acts as the project lead here. The project is already pre-structured into work packages. This intends to give the inexperienced first semester students in particular a framework or common thread for their project. However, in compliance with the PjBL characteristics the outcomes of the work packages are not predetermined and the students have space for their creativity and can experience different tools and methods to solve the driving problem. They are involved actively in the process of developing and designing the sustainable energy system concept, which represents the intended end product of the project.

Each workshop session starts with an opening by the project lead (teacher), where the tasks and sub driving questions for the current work package are presented. Working material is provided through the online learning platform Moodle. Tools and software needed for the next session are introduced in videos, so that the students can prepare themselves in advance. After the weekly introduction, the students work mainly autonomously in teams of three. The teacher takes on the passive role of a facilitator and provides support if needed.

The project is divided into three phases. Table 1 gives an overview of these and their corresponding work packages, including the number of weeks dedicated to each work package. Further, the used methods for each work package are described.

In the preparation phase, the students get an introduction in skills they need for their work in the engineering office. They are already working in teams, but the composition of the teams is still flexible and vary each week in this phase. This serves the purpose that the students should first get to know each other better before forming fixed teams, since they are new to the university. The students learn how to organize themselves and communicate within their teams and how to communicate with the project lead. They write a guideline about the characteristics of scientific literature, how to find and identify it. Furthermore, they deal with the appropriate documentation of results and work progress.

From the fourth week onwards, the students form fixed teams of two to three by their own choice, which remain unchanged until the project ends. The execution phase starts, in which the actual project is processed. Each team member documents their teams project progress and weekly results in a personal project journal. In addition to that the students also write down personal reflections of the project process in their project journal. At the end of the week, the journal entries are uploaded to the Moodle platform and reviewed by the project lead. Review criteria are completeness, technical correctness in the documentation and accuracy of the notes as well as the focus on the project aims. The personal reflection part is not subject to a separate assessment, but should be structured, self-reflective and critical.

During the project execution phase, the students work on four different work packages of interdisciplinary topics. Each team will work on the same work packages. The teams' project outcomes, nevertheless, will differ since each team will make its own decisions and use its own approaches.

Table 1. Content and methodological structure of the workshop

Project phase	Work package	Methods and social forms	Number of weeks
Preparation	Communication for teamwork	Group discussion, plenum discussion	1
	Research on scientific literature	Literature research, report writing	1
	Documentation of work progress	Investigation of negative examples	1
Execution	Photovoltaic plant	Inquiry-based learning with simulations, software usage	3
	Battery system	Literature research, choices based on solid justifications	1
	Solar thermal system	Visit of a real plant	1
	Pellet heating system	3D-designing, 3D-printing, peer review	3
Completion	Presentation of the energy concept	Oral team presentation	2

The project begins with the design of a photovoltaic plant for the house. First, the students investigate the solar orbits during different seasons by simulations to understand how to find out the perfect position for the plant on the roof. In the following two weeks the students use the designing software PV*SOL to plan the actual photovoltaic plant. The next work package deals with the dimensioning of the battery system. Here the students examine different types of battery technologies and should give a recommendation for the clients' house, based on literature research. After finishing the electrical supply for the house, the students plan the thermal supply. A solar thermal system is to be installed to heat the domestic hot water. The students visit the solar thermal system of the university and learn about the elements of the system and their functionality. Afterwards, they have to design a system diagram for the clients' house, in which they have to apply the newly gained knowledge from the inspection of the actual plant. In the following three weeks, the students plan a storage room for pellets to be used in a pellet heating system. In this work package, the students build a ramp structure to slide the pellets to the exit of the pellet room towards the heating. The work package includes designing the ramp in Autodesk's 3D software environment Tinkercad, creating it in a 3D printer, and testing and evaluating one's own ramp and that of another team.

In the last phase, the project is concluded by a team presentation in which the students present their elaborated results and thus their developed sustainable energy concept for the house as their end product of the project. The audience consists of the other teams, the project lead and other members of the engineering office, represented by teaching staff of the university. The engineering office members and the project lead evaluate the presentations of each team and decide which concept is finally realized and presented to the clients. For the assessment of the whole workshop, team and individual evaluations are combined. The grade is composed of 50% each of the evaluation of the team presentation grade and the weekly project journal grade.

In this implementation of PjBL, all the main characteristics presented in section 2.1 have been successfully integrated. Nevertheless, the point of interdisciplinarity might not necessarily be implemented as it was originally intended. The workshop is composed of work packages that all come from the field of energy engineering. However, energy engineering itself is interdisciplinary and consists of many different disciplines, such as electrical and thermal energy generation, distribution and storage, different sorts of renewable energies and energy efficiency. Therefore, the workshop demonstrates the interdisciplinarity of energy engineering so that first-year students get an orientation in their chosen field and a first impression of the interdisciplinary challenges they have to face during their studies and their further professional life as energy engineers.

4 EVALUATION AND RESULTS

4.1 First survey and interviews

After the first realisation of the workshop in winter semester 2020/2021, the students took part in an online evaluation consisting of a questionnaire. The intention of the evaluation was on finding out how the students assess the implementation of the PjBL elements, the engineering office scenario itself and the learning materials from their point of view and where they see potential for improvement. Additionally, five students had been chosen for a guided interview to obtain more detailed insights of the evaluation of the PjBL concept. The results showed a high acceptance of the concept and the idea of the engineering office setting. The level of difficulty of the work packages was assessed as mostly appropriate. The students could well imagine that they would have to complete such tasks as real student trainees, since they never had to bear the complete responsibility for the work package alone, but rather work alongside the permanent employees from the engineering office. The above-mentioned challenges for students could be also mastered well mostly. Especially the lack of teamwork and project management skills was well supported during the preparation and execution phase. The students were motivated and enjoyed their creative space during the project.

According to section 2.4 one main challenge identified was the difficulty in implementing the authentic learning environment. This was also apparent in the interviews. The engineering office setting was not always present and authentic for the students. Sometimes they forgot that they had to take on the role of student trainees. The change from the participant in a university course to an employee in an engineering office was occasionally difficult for them. Moreover, it was not always easy to see the teacher in the role of the project leader rather than the university member and rater.

4.2 Exploratory survey on student’s reality of an engineering office

To enhance the understanding of the students’ imagination and mental picture of an engineering office, a written survey with open questions within a questionnaire was conducted at the beginning of winter semester 2021/2022. Uninfluenced by the following confrontation with the designed engineering office setting in the workshop, the students should describe how they imagine an engineering office, what they associate with that term and what experiences they might already have gained. The questionnaire contained questions like:

‘*Name the first 3 words you associate with the term engineering office.*’

‘*How do you recognise an engineering office? What do you think is typical for an engineering office?*’

‘*Have you worked in a real engineering office yourself or do you know someone who works or has worked in an engineering office?*’

The majority of the students have never worked in an engineering office themselves or know someone who does. Mostly, they described typical elements of offices for architects or civil engineers, like open space offices and technical drawings pinned onto the walls. These elements are in contrast to typical classrooms of universities.

The results of the survey will therefore be used to create a more suitable learning environment for the PjBL-workshop, which will be designed as the students imagine an engineering office and will look less like a classroom. The intention is to overcome the classic teaching patterns and to literally give the new roles of students and teachers a new room to develop.

5 CONCLUSION AND OUTLOOK

This paper introduced a PjBL-workshop for freshmen energy engineering students with details of its content and methodological structure. As already mentioned by Strobel et al. (Strobel et al. 2013), the main challenge for the implementation also was identified as the creation of the authentic problem-solving environment, since what is authentic for students is not necessarily what teachers consider it to be. Although the majority of the participating students have not yet had any direct or indirect experience with an engineering office, they already have an image of it. Influences of this on their perceived authenticity of the PjBL-setting will be investigated in the further study. This ongoing study will also examine the effect of the perceived authenticity of the PjBL-setting on factors like the study motivation, the intrinsic motivation for the project or the individual and situational interest for the project topic.

Strobel et al. (Strobel et al. 2013) additionally pointed out, that there is a need for robust models and operational definitions of authenticity, especially in engineering education. Investigations regarding the effects of authenticity on learning outcomes are needed.

Therefore, in further steps of this study, a model of perceived authenticity, including an operationalisation, will be developed on the basis of the presented PjBL-workshop concept.

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RESHAPING THE BIO MEDICAL CURRICULUM TO INCLUDE SOCIALISATION AND SUBJECTIFICATION

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ABSTRACT

University students are asked to become all-round human beings, knowing how to be engaged in Engineering in the future, as well as wholly socialised and going through personal development steps. However, how and where are the students supposed to acquire these skills? Do we already have them in the Higher Education programmes and curricula? This article explores low threshold steps that can be taken to tweak the curriculum and implicit professionalisation of staff towards incorporating transversal skills and reflective activities that allow students to develop to their full potential.. One is a roadmap

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Workshop identifying guiding principles and touchpoint activities for curricular change. The other is a survey on how transversal skills are currently thought to have been embedded in the curriculum

1 INTRODUCTION

According to Biesta (2009), the current pedagogical assignment for education is the tripartite development of students on qualification, socialisation and subjectification. Qualification ensures our students in Higher Engineering Education become competent in one or multiple disciplinary engineering fields. Socialisation relates to students becoming aware of the values and norms embedded in academia and the professional environment they will enter after graduation. Subjectification is an ambition to develop the qualification, socialisation and who they become. This pedagogical ambition requires repurposing and (re)shaping the university's curricula.

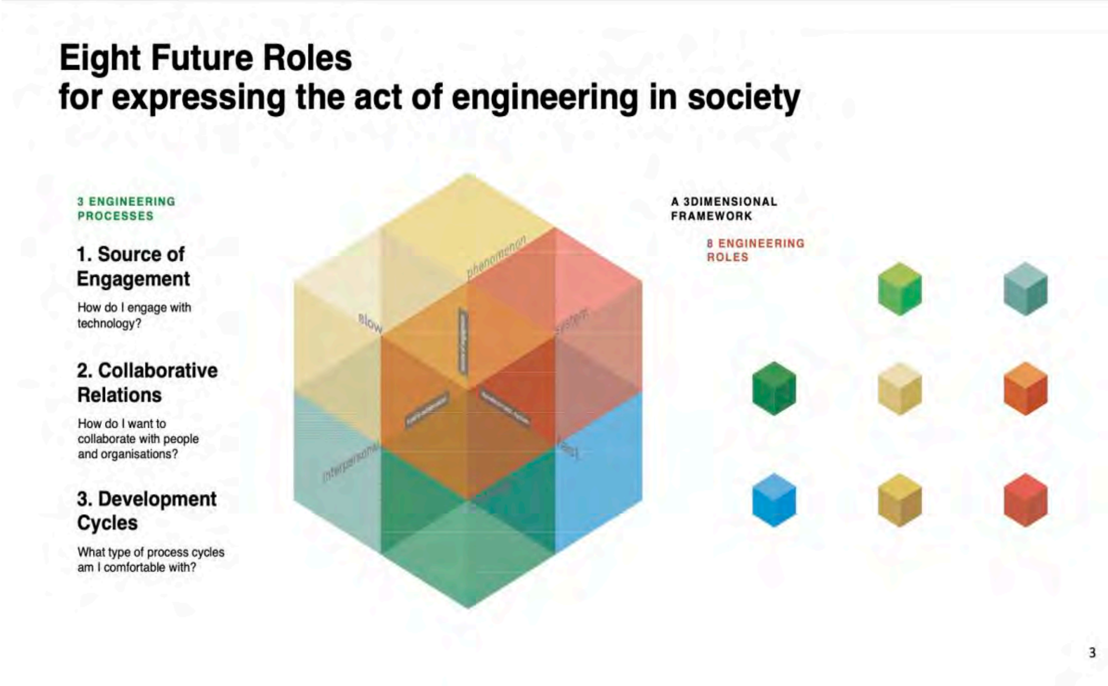


Fig 1. Engineering Roles

In the Bio-Medical Engineering (BME) programme, we have embedded a design-based vision of the future engineer. The Vision in product design methodology has been used to create engineering roles with the involvement and interviewing on expert interviews in the field, literature reviews and validation workshops. The Vision suggests three dimensions our students will encounter in their future engagement with technology. These dimension of engagement with technology, collaboration models and fast and slow production cycles helps students to become all-round engineers (Klaassen et al., 2020). The emergent engineering roles from the dimensional framework are a guiding tool for going through a reflective cycle of development leading to subjectification, socialisation, and qualification. Transversal skills are used to ground the socialisation process of future engineers in the BME context, and qualification is supported by the acquisition of BME knowledge and skills and subjectification through role-focused reflections. Table 1 includes an overview and its intended relationships and as expressed in the BME curriculum.

Table 1. Framework for curriculum adaptation

Pedagogic aspects (Biesta 2014)	**Dimensions Engineering Roles vision (Klaassen et al. 2019)**
Subjectification:	**Engagement with technology**
Engineers should be able to adapt to a changing environment,	Phenomenal/societal challenges addressed.
Engineering Role identification	
Take agency for their own learning/learning path, in which *agency* is defined as the ability to act based on your reasoning and understanding yourself in context.	Reflection and positioning concerning individual engineering roles in relation to the world.
Socialisation:	**Collaborating in technology**
Use engineering topics to interact with the world,	Preferred ways of working on basis of interpersonal trust or via rules and regulations of a system
Engineering Role in action	
Take responsibility for shaping future practices,	Reflection on preferred ways of working as an engineer
Qualification:	**Dimension**
Develop a continuous lifelong learning loop.	Acquisition of skills/ knowledge/ attitudes for slow and fast development cycles of production
Engineering role application	
Critical assessment of professional standards through engineering knowledge/skills practices	Reflection on theories, tools and methods needed.

2 METHODS

In this curriculum development process, we have chosen to determine a roadmap for implementing an environment beholding these pedagogic and dimensional elements from Biesta and the Vision of the future university (Biesta, Klaassen et al.2020). The idea was to create a maximum impact with minimal effort from the teachers involved N= 6. The 1st part of the curriculum development consisted of a start/– stop/continue approach to activities within the curriculum. To prepare teachers, we have undertaken activities that supported the creation of an understanding of the courses concerning the

Vision, mapping where we wanted to operate/tweak courses on a meta-level and designing supporting materials needed for teachers to implement the created framework. In general, activities to generate implementation or guiding principles included workshops with teachers, interviews and surveys with students, teacher surveys on sub-elements etc. This paper reports on one of these workshops and a teacher survey.

In this particular teacher workshop, a brainstorming activity was conducted on a student learning journey map with touchpoints within the Master curriculum that served as a timeline for embedding educational interventions or desired activities in education. This brainstorm has successively served as a basis for input into a roadmap, including six guiding design principles for curricular development, that included the three pillars of Biesta and the dimensional features of the future university. The intention was to support teachers in the programme in identifying; how these framework ideas could apply to their courses, what is already present in their courses and whom they can ask for help if they want to change their curricular design. These principles will allow them to easily insert and embed the new merged Vision on education, addressing both Biesta and the future vision model. In a follow-up workshop, they were asked to rephrase their learning objectives to align the vision framework with practical courses.

The teachers of all the courses N = 12 were also asked to fill in a questionnaire to find out which reflective, contextual skills and engineering skills were already used in the 18 courses offered within the master curriculum. Teachers could answer: (1) students are already trained on these skills, (2) not trained on these skills and (3) not trained on these skills, but I would like to add them to my course. The skills were provided with an explanatory definition.

2.1 Workshop Assignment and Methodology

According to the developed principles, the university is required to realise a safe context in which experimentation and failure are a part of the learning process. This idea of a safe context propagates programmatic assessment in which multiple performance measure moments are embedded, and 360-degree stakeholder input and stepping away from past failure are new focal points. These six Guiding principles steps described in the next section, should facilitate the reshaping of this curriculum endeavour and support students in going through iterative rounds of reflection related to subjectification, socialisation, and qualification elements. Reflection encompasses "whom students want to become with help of the engineering dimensions", "how students act in the outside world", "how students can understand and influence future practices and "how students can change the future

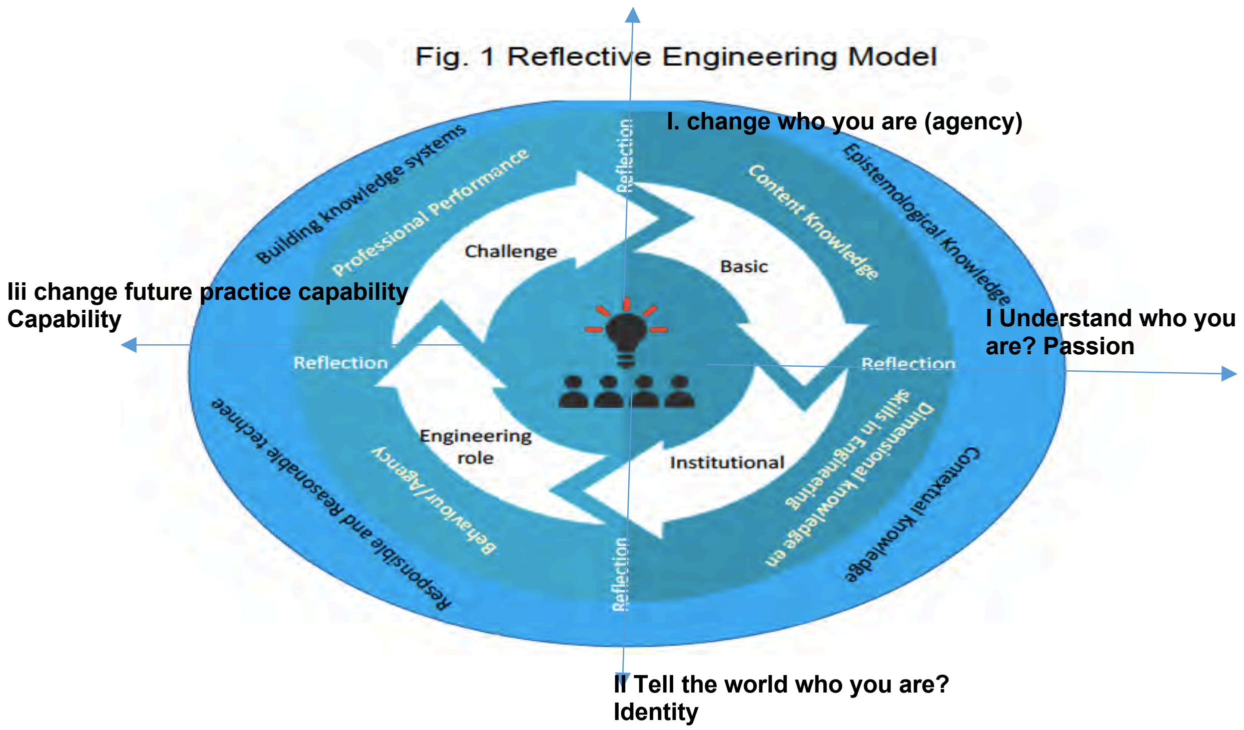


Fig. 1 Reflective Engineering Model

Skills and knowledge are part of the light blue and turquoise circle in Fig. 2. of the reflection cycle. Disciplinary & epistemological knowledge for medical, biological, and engineering knowledge and what is probable, possible and impossible is necessary for existing and changing practices. Engineering skills help students position themselves in practice and make technical decisions. Contextual skills include becoming aware of and responsible for the consequence of actions (ethics) that are taken or not taken concerning doing, saying and knowing in practice. Furthermore, finally, reflective skills include understanding one's position in context and practice and being capable of acting based on one own reasoning (Trede's, 2019). However, the key question here for the teachers is on how to embed this in their curriculum or programme. The Roadmap workshop was designed to answer this question.

3 THE ROADMAP WORKSHOP

In a workshop setting, these profiled ideas have been benchmarked with the lecturers, who mainly favoured adopting these suggestions while equally discussing further refinement and adaptation possibilities within the curriculum along a transition moment timeline. Transition moments are, for example, choosing a master track or a thesis topic. Suggestions mainly focused on providing role models embodying the engineering roles in the BME field and learning from interaction with these people.

Teachers were, however, equally expressing concerns about the need for more time to embed these elements and for the students to adapt these skills. E.g., the question is if they need to be assessed in the curriculum and when, in reflection documents, who will do the work. Who has the ownership of reflection documents etc? Moreover, whether these really add value to the curriculum.

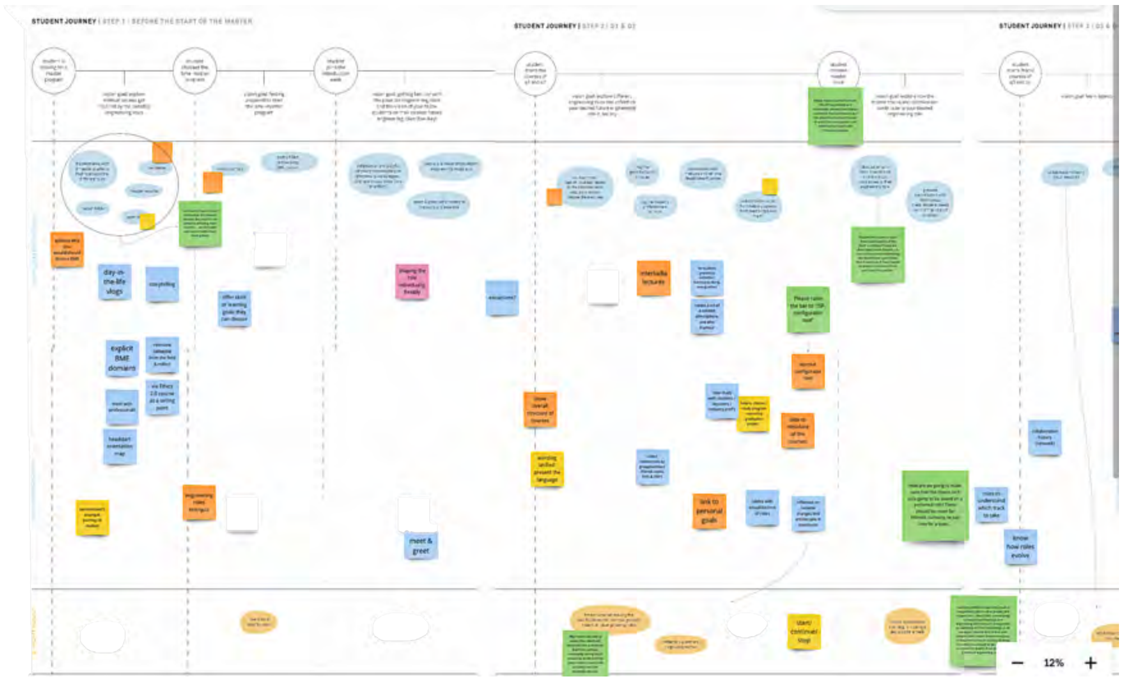


Fig. 3 ideas to embed in the curriculum (post its on roadmap)

Nevertheless, the workshop resulted in 6 guiding principles for curriculum design that would meet the engineering vision's original dimension and address the pedagogical assignment of Biesta. Before the Master, students should be given ownership of their learning experience, providing information about the possible engineering roles and reflective activities to motivate and challenge their attitudes. This reflection might be realised at the open day, introduction day or through other introductory media, such as conversations with people from the field, a video documentary of "a day of…".

Another option is the focus on diverse role models presented in the kick-off week, which students use to reflect upon the responsibilities and mission the future engineering students will likely encounter. In the first workshop, students presented their future engineering manifestos (read reflections) in groups. This manifesto helps students decide on their desired Master's track. During the Master, there were many more suggestions for embedding ownership, such as reshaping assignments into challenges involving external stakeholders, flexible choosing which challenges to work on in a team and using engineering roles to set up personal goals, translating (transversal) skills into the learning objectives, and contextualising the course to a greater extent

3.1 Guiding Principles

01 Translating own reasoning into personal goals (subjectification): Setting personal learning goals is supported by identifying a knowledge-skills-matrix and in which courses these can be acquired within the BME master. BME Knowledge and Skills are categorised at different levels; disciplinary, engineering skills, contextual and reflective skills. A reflection portfolio might support the evaluation of these personal goals.

02 Experimenting with forward reflection (subjectification) – reflection is introduced using future engineering roles we expect will be relevant in 10 years and can guide students and help them shape their futures. Analysing the knowledge, skills and development path of favourites in the field on a dimensional level helps to shape a personal future profile, using principle 01 to get there.

03 Taking an ethical stance and acting responsibly (socialisation) – is about being aware of what product and research results are distributed and adapted into the world. Reflections on how they interact with the world and their actions' impact are vital socialisation aspects for the students (Walcott et al., 2019). Case studies and explicit evaluation of challenges in team settings should guide the learning process.

04 Supporting pivotal transition moments – students discovering their way of being and supporting the transitions to help students get a more straightforward learning path is pivotal for subjectification. Students presenting and upgrading their manifesto regularly with supportive feedback from peers and professionals help navigate the pivotal moments.

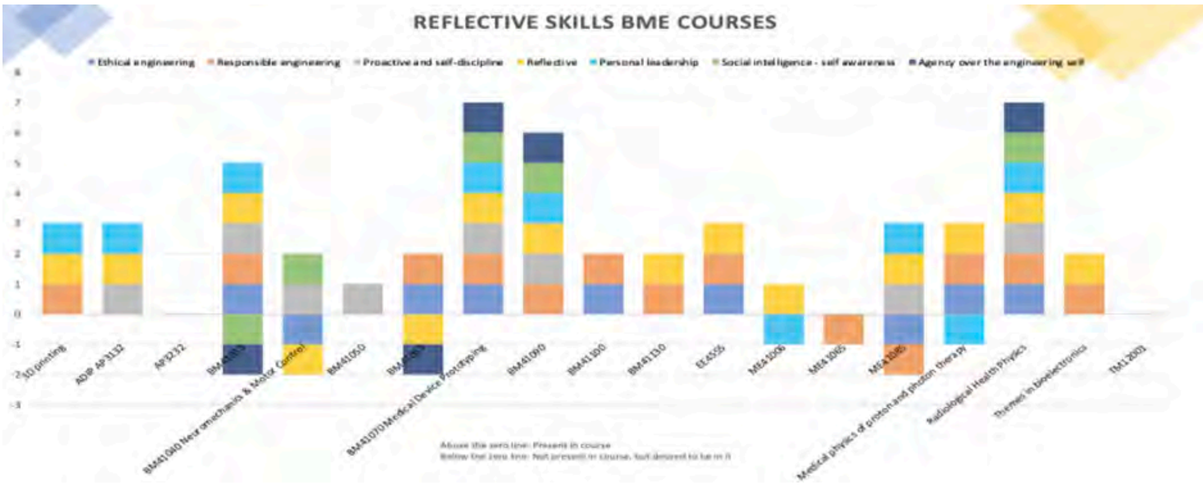
05 Studying in an ecosystem learning environment- (socialisation) requires the students to operate in contextualised environments in interaction with the world (stakeholders in organisations, businesses, and citizens. Therefore, students need informed visions, critical thinking skills and evaluative judgment to assess how to operate in the ecosystem (Spencer-Keyse et al., 2019).

06 Exchanging insights and experiences – the joint dialogue at different levels about pertinent topics are crucial to socialisation, including peer feedback, outside professional involvement, and group discussion with teachers, mentors and guests (Goggins et al., 2022, Diez- Palomar et al., 2020)

Getting the six basic principles into the learning objectives in language that is accessible and provides a joint reference frame allows the teachers to emphasise to students the need for specific skills training. The credit structure can support it and provide an overview of the skills growth within a specific principle. A reflection portfolio and the continuous looped learning that will occur through reflection will allow students to adapt better to different work contexts. Working group dynamics, debates and peer reviews should support students in innovating and changing future practice. Alternatively, after the workshop, more attention can be paid to creating a dashboard summary and enhancing reflection on the professional transition in the workforce.

4 RESULTS TEACHER QUESTIONNAIRE: EMBEDDING SKILLS IN THE CURRICULUM

The second part of mapping the opportunities for change in the curriculum along the framework while making use of the guiding principles was to find out the already used skills in the curriculum. We have used a questionnaire to investigate the knowledge and skills distribution present in each tiers of Fig. 1. The questionnaire on skills included in the courses shows skills in coloured blocks representing the different skills and, at the bottom, the different courses in the curriculum. The questions (1) What do you already address in your course and (2) What is not yet used in your course are depicted above (used) and below (not used) the zero line in Fig. 4,5, and 6. What might be used is not represented



in the graphs.

Fig. 4. Reflective skills

In Figure 4, reflective engineering skills such as responsible and ethical engineering, social intelligence and awareness, proactivity and self-discipline, agency and personal leadership, and reflection skills have been asked. The graph shows that, for example, agency training only occurs in three courses with a particular design focus. (prototyping/ health physics and BME 41). The other teachers need to include this reflective skill in their courses or know if they do or do not. However, responsible, and ethical skills are included in 11 and 12 courses, respectively.

Furthermore, one course, for example, has only one reflective skill included self-discipline; the other skills are not named, as in not occurring in the course, which makes one wonder. A few more courses have this exact visualisation. Do the teachers not know what skills are addressed in their course? Do they not understand what is being asked? Do they address it, but do they not assess it? Do they only do it a little? The results were a reason to engage the teachers in a more elaborate discussion

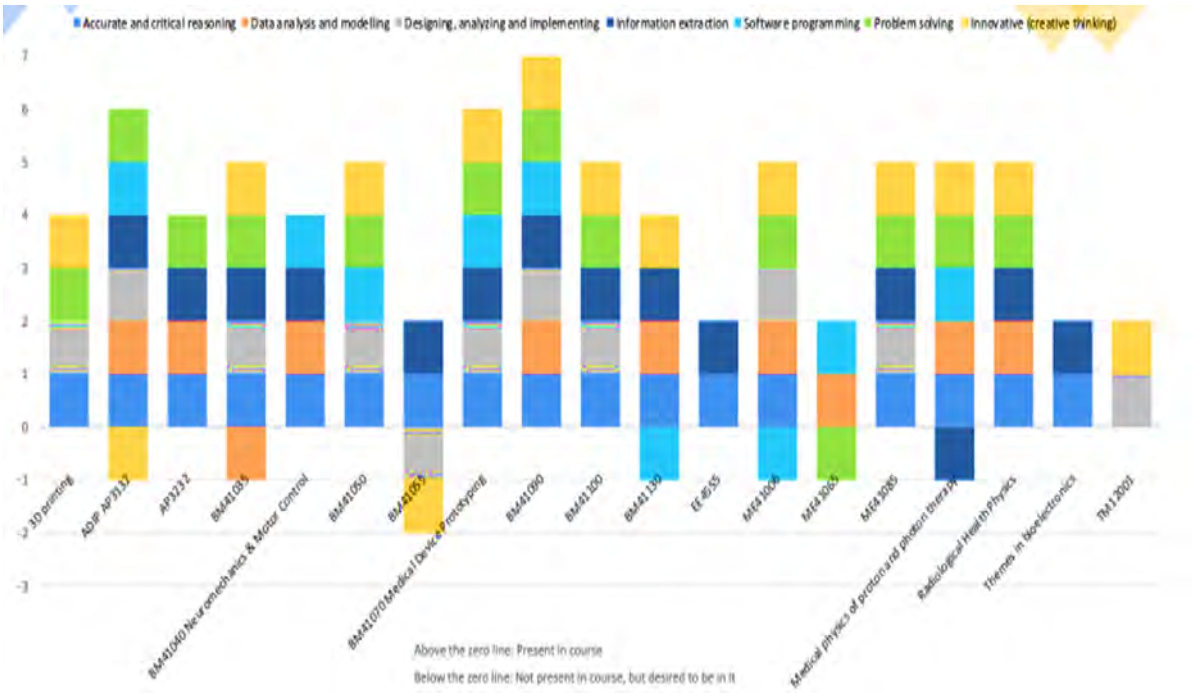


Fig. 5. Engineering skills

In Fig. 5, the Engineering skills are somewhat better recognised. Eighteen out of nineteen of the courses address accurate and critical reasoning. Information extraction happens in thirteen courses. Twelve out of nineteen address problem-solving skills and innovation (creative thinking). In ten courses, design, analysis, and implementation occur. Data analysis and modelling are not necessarily together with software programming in nine courses.

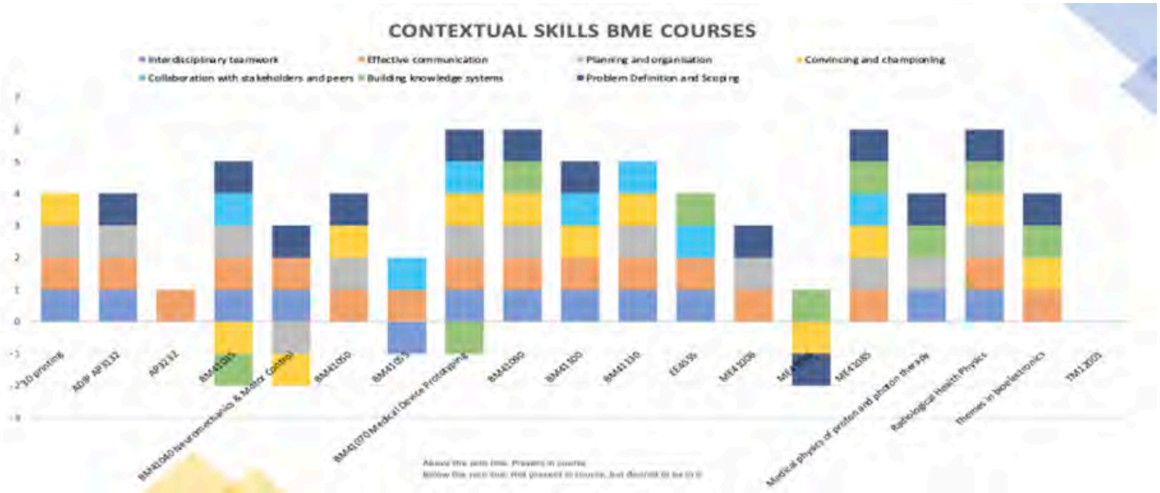


Fig. 6. Contextual skills

Figure 6 represents Contextual skills acquistion, for example, twelve courses address problem definition and scoping skills. Surprisingly, these only sometimes occur together in the same courses where problem-solving is addressed. In eleven courses interdisciplinary teamwork occurs, of which only six also address engagement with stakeholders and peers. Whereas one would expect this to be more equal, doing interdisciplinarity assumes teamwork and stakeholder involvement and contribution to external knowledge systems. Only seven courses contribute to external knowledge systems or disciplinary knowledge building. These are, again, different courses. To make sense of these outcomes, we need some serious, cross-tabular mapping in which the nature of the courses is also addressed and a follow-up conversation with the teachers about interpreting the results.

In a follow-up workshop in discussion with the lecturers, it appeared that not everyone had equally understood the explanation of the skills and their definitions, making the results difficult to interpret. Nevertheless, the next step is to reformulate learning objectives and recalibrate if, when and where the desired knowledge and skills are addressed in the curriculum.

5 CONCLUSIONS

This paper discusses a few design-based steps that may change the Master Programme BME with minimum interventions according to the six guiding principles explained in the results section. This approach has been chosen to alleviate the high work pressure on teaching staff and the fact that Covid-19 has seriously impacted the teachers' well-being. Teachers have been open to discussion and making the best of it. However, it was only sometimes easy to take them along this ongoing road of change and provide them with much-needed ownership to adapt to a new framework. We have had valuable discussions with teachers, resulting in constructive collaborations to press forward towards a new master curriculum slowly. From students' surveys reported elsewhere, we found a positive impact on student's professional capabilities, particularly in personal development (Klaassen et al., 2022). However, much must be done to achieve a more persistent and sustainable change.

6 DISCUSSION AND LIMITATIONS

In this hands-on design-based study, we have provided insight into a design-based approach towards curricular change. The development of a road- map proved to be a suitable means for calibrating opinions and alignment of reference frames. On the other hand, the survey provided ambiguous data that could not be clearly interpreted and needed follow up.

Each step in this process included a double diamond approach, from brainstorming new elements to bringing them back to the curriculum, sharing activities and interpretation, to converging towards one meaning and interpretation. Therefore, these steps have been used for a resocialisation process into engineering education and re-establishing teacher identity for the future, more than anything else.

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ENGAGING STUDENTS THROUGH INNOVATION IN COMPUTER SCIENCE EDUCATION

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Conference Key Areas: *Engagement with Society and Local Communities, Engagement with Industry and Innovation*
Keywords: *Computer Science, Innovation, Students´ engagement*

ABSTRACT

When an important course *Entrepreneurship and Innovation* is cancelled, it is still possible to incorporate innovation into the programme and provide students with opportunities to enhance their specific academic skills. This contribution addresses how the innovation activities have been implemented in two bachelor programmes in computer science at Kristianstad University in Sweden.

The survey results shows that the students wish for the university to continue offering these innovation modules and that they encounter similar modules in upcoming courses. The students felt that the module increased their understanding of the subject and their perception of their own skills.

1 INTRODUCTION

The goal of the innovation activities is to equip students with essential skills and abilities like developing technical and analytical skills, communication, collaboration, problem-solving, critical thinking, and creativity to prepare them in their professional role, to actively contribute to their workplace and work to identify and find innovative solutions to societal challenges.

How can these skills be effectively integrated into the programme(s) in the absence of a dedicated course?

To achieve this goal, the programmes provide project-based learning to enhance the learning experience for students and, additionally, include the events like *Imagine* or *Hackathon*, where students work in teams to develop innovative solutions to complex problems. *Imagine* event provides an opportunity for students to showcase their skills and creativity and receive feedback from experts in the field. It is offered at Kristianstad University several times a year with different focus areas linked to the University's profile area of environment, health and water, which for computer science students give a chance to work interdisciplinary. *Hackathon* event is provided by older students and the goal is to challenge and encourage younger students in programming.

By providing students with practical experiences and exposure to modern technologies and teaching methodologies, the programme prepares them to navigate the ever-changing demands of the workforce. The incorporation of team-based learning and events enhances students' collaboration and creativity, providing them with the skills (effective communication, leadership, project management) they need to succeed in the modern workplace.

1.1 Innovation

Many definitions and interpretations of innovation are used in different contexts and disciplines. The most widely accepted definition of innovation is described in the Oslo Manual [1] as:

> *"An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations."*

([1], line 146, p.46)

Baregheh et al. [2] present a comprehensive study based on comparison of 60 definitions of innovation collected from various disciplines. Based on that they propose a following diagrammatic definition:

> *"Innovation is the multi-stage process whereby organizations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace."* [2]

The definition of innovation presented by Baregheh et al. [2] is most relevant to computer science students because of its "multi-stage process" as well as it emphasizes the importance of transforming ideas into new or improved products, services, or processes. This aligns with the goals of many projects and students' activities as HackaThon and Imagine (described below), which involve creating new software or to meet user needs or solve problems.

1.2 Hackathon

A hackathon is an event, usually over a short time such as 24 or 48 hours, where programmers, developers, designers, and other technology enthusiasts engage in rapid and collaborative engineering, typically in a competitive setting. Participants work in teams to create solutions for specific challenges or to develop innovative applications, often with a focus on a particular theme or goal. The goal of a hackathon is to encourage creativity, innovation, and collaboration among participants, and to produce a functional prototype or finished product by the end of the event. Hackathons can be organized by companies, educational institutions, government agencies, or other groups, and are a popular way to promote technology education, entrepreneurship, and innovation.

1.3 Background

Kristianstad University is a small but dynamic university that strives to be among the most attractive universities in Sweden. The university's goal is to strengthen its reputation as a high employability for students and gain recognition outside of Sweden. To achieve this, the university has implemented various measures such as worked-based teaching across all programs and internationalization, which includes, among other things, adapting programs to student and teacher exchange. In addition, the university has established academic tracks, sustainable development, gender equality and innovation.

To comply with the university goals, the computer science programmes are revised around every three years. Students, alumni as well as the companies have a big impact in these revisions.

1.3.1 Entrepreneurship and Innovation (2011 – 2022)

The course Entrepreneurship (IE520A) was introduced for the 3rd year computer science students back in 2011 because of a revising the programmes with adaptation to the university’s vision. In 2015 the course has been revised by adaptation of Innovation (Entrepreneurship and Innovation, IE300A). This course was taught until 2022 with small revisions (IE301C)[1]. Unfortunately, with new revision and more focus on computer science, the course was cancelled. However, innovation part became implemented in new programmes in a new way – as an innovation track.

The main question was whether and how it is possible to incorporate innovation into the programme when a course *Entrepreneurship and Innovation* was discontinued. What should be included and excluded.

[1] Course syllabus - Entrepreneurship and Innovation - 7,5 credits - IE301C , English | HKR.se

1.4 Related work

Innovation at higher education brings also different views. In OECD Report from 2016 [3] can we find outcomes of different projects, like “Innovation Strategy for Education and Training”, “Innovative Learning Environments”, and “Open Education Resources”. Here the focus lies on innovation / digital technology for learning, e.g. innovative pedagogic models; simulations as a low-cost access to experimental learning; e-learning; international collaborations; as well as for implementing and evaluating innovation in the education system.

Hoidn et al. [4] review the effectiveness of problem-based learning (PBL) compared with traditional approaches in higher education teaching for developing skills for innovation. The report explores the extent to which PBL can develop discipline-specific and transferable skills for innovation like social and behavioural skills such as motivation, interest, self-confidence, self-directed learning and teamwork.

Kumar et al. [5] discuss how educators straggle to improve, re-invent existing courses, re-organize majors and carve out new majors. The authors present in short some of the innovations that have been introduced into the undergraduate Computer Science curriculum. In most cases the students do groups activities and/or projects.

Daimi and Rayess [6] shows an importance of Entrepreneurship course in the curricula of Computer Science and Software Engineering education. They motivate that “computational thinking will govern the process of innovation to produce new software products and technologies, and entrepreneurial thinking will establish the foundations for marketing these products and technologies.” The authors introduce a design of a software entrepreneurship course, its rationale, description, objectives, outcomes, assessment and present case studies and projects. The goal of the course is to bridge the gap between creating products and creating marketing opportunities.

Zhang and Dong [7] present a need of innovation in teaching in China as three aspects: “teaching reform, training system and a platform for industry-university-research cooperative education”.

To consider innovation as a process, it is crucial to provide training to students from their first course, and it is equally important to engage and motivate them right from the start. An interesting study about the engagement of first-year students in large courses during the covid-19 was done at Swedish university [8]. It explores two successful cases of how active learning, togetherness and engagement can be created. The authors experienced that the students had actively participated in the arranged activities and the course passing rate was higher compared with the face-to-face teaching. The course evaluation also showed that the students were satisfied with course contents and various course activities.

2 METHODOLOGY

2.1 Action Research

Implementation of innovation activities is based on the action research (see Fig. 3) where a group of teachers involved in it discuss and improve the process in regular meetings.

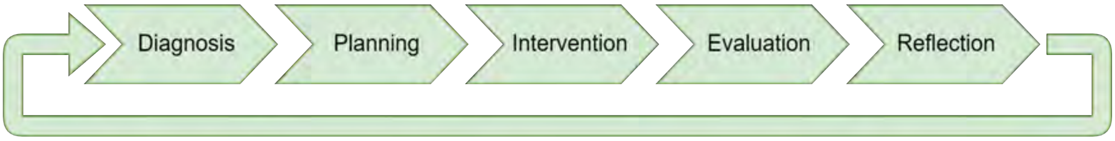

Fig. 3. The cycle of five stages in action reseach. [9]

2.2 Survey

At the end of the course that was held in Spring term of 2023, a survey was distributed to the students. 45 out of the 60 participating students responded.

3 STRUCTURE OF COMPUTER SCIENCE PROGRAMMES WITN INNOVATION TRACK

The following figures (Fig.1, Fig.2) show two computer science (CS) programmes with marked courses that includes innovation activities. The courses marked with the dots are the courses where including innovation aspects is optional. In both programmes, the marked courses include the individual or group projects.

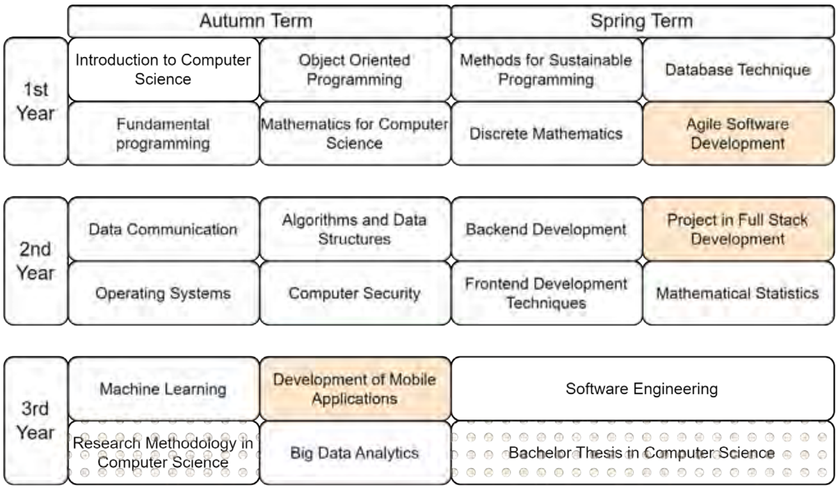

Fig. 1. Bachelor Programme in Software Development[2]

[2] Programme syllabus - Bachelor Programme in Software Development - TBSE2 , English | HKR.se

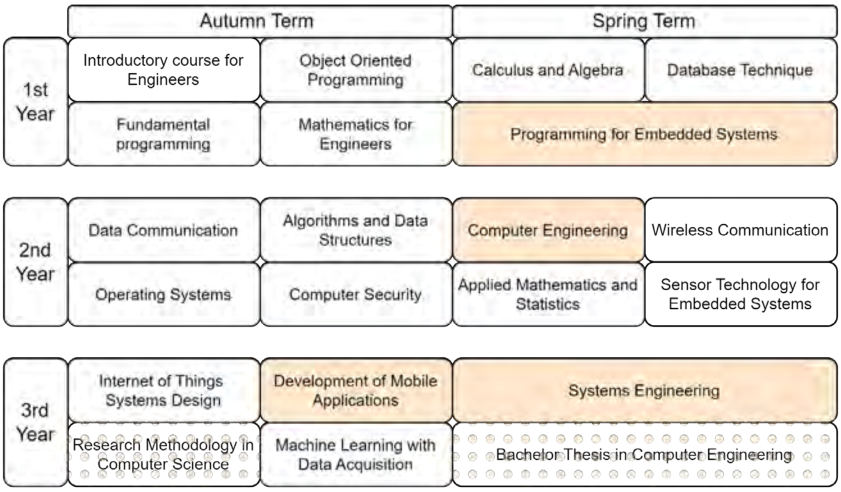

Fig. 2. Bachelor Programme in Computer Science and Engineering, Specialization in the Internet of Things[3]

3.1 Development of Mobile Applications course, DA324A[4]

The course Development of Mobile Applications is offered to both programmes. It includes lectures, labs, and a group project. The aim with the course is to teach students Android development and how to apply that knowledge to real-world problems. During the project work, students are expected to utilize their innovative skills to create Android applications that are useful for society.

The project work is conducted in collaboration with the university's department, which primarily focuses on connecting the university with society through an event/workshop called ***Imagine***[5]. All programmes offered by the university are eligible to participate in the Imagine workshop, which means that there are many innovative areas with various issues that university students can work on.

At the Imagine workshop, one representative from a company joins a student group to collaborate on designing features that would address a particular issue faced by the company or society. However, it is also possible for representatives from other area of society, such as hospital personnel, to contribute by presenting and discussing issues in their respective environments. In this way, students can work to find innovative solutions to a variety of challenges.

The following are some examples of Android applications developed based on the issues presented during Imagine event:

- In 2018, computer science students joined Imagine workshop with nursing students to come up with innovative solutions for hospital care[6]. The collaboration resulted in the

[3] Programme syllabus - Bachelor programme in computer science and engineering - TBIT2 , English | HKR.se

[4] Course syllabus - Development of Mobile Applications - 7,5 credits - DA324A , English | HKR.se

[5] Imagine – En innovationshöjande aktivitet för studenter | HKR.se (in Swedish)

[6] Datavetare ger draghjälp på ToY Imagine | HKR.se (in Swedish)

development of several various applications, and an example of one such application can be found here[7]

- Despite the pandemic, the Imagine workshop was successfully conducted online[8].
- The workshop held this year involved both of our data science programs and included 12 companies with 15 app ideas or questions. The quality project was completed by 15 student groups, each comprising four students, who developed a mobile application as part of their coursework.[9]

3.2 Systems Engineering course, DT337A[10]

The Systems Engineering course is the second and last project course in the Engineering curriculum. This course is conducted concurrently with the thesis, and the students work on the same project in both courses but focusing on different aspects. In the thesis course, the emphasis is on the scientific part, while the systems engineering course focuses on prototype development. This construction allows the students enough time to develop an innovative prototype as well as evaluate it within the thesis. The prototype development project involves both hardware and software aspects. The students have the possibility to work on the project in an industry as well as working by themselves at the university. Both industry projects and independent students' projects are often innovative.

Examples of projects include:

- Smart heating control: This prototype is used to control heat to the facilities by an actuator and measure system temperatures. The method used to control the system was a deep learning model implemented in the prototype edge device classifying the system's different behaviours, preheating, heating and cool down. The prototype was installed in a real house and evaluated for several weeks.
- Preventing mould damage in attics: This prototype notifies property owners when environmental conditions in attics are favourable for mould growth. It was tested on site in an attic.

3.3 Other examples of engaging students

3.3.1 HackaThon at HKR. 12th of November 2022, Saturday, 14:00 – 18:00.

This hackathon was organized by senior CS students and took place on campus and online. The event was aimed at all CS students. The tasks were adapted so that everyone could do at least one task. Students started with an easy task and slowly progressed to more difficult ones. All the tasks were designed by a senior student, who described the experience as "a great learning opportunity for me." The students could participate individually or in groups and could choose any programming language. The invitation letter encourages first-year students not to be intimidated by

[7] EldHelp gives the elderly independence everyday, English | HKR.se

[8] Förbättrad miljö och minskat matsvinn prisas på innovationsevent | HKR.se (in Swedish)

[9] Studenter skapar app för global pant mot nedskräpning | HKR.se (in Swedish)

[10] Course syllabus - Systems Engineering - 15 credits - DT337A , English | HKR.se

difficult tasks, but to view them as opportunities to solve creative challenges and learn from the experience.

Senior students described the hackathon as a social coding event that brought students together to solve coding tasks. The level of experience didn't matter, the focus was mostly on having fun and challenging themselves with like-minded people.

Feedback from the 1st year student: “The hackathon was fun and gave me insight on how to think in different ways regarding coding. And I gained a lot of experience from solving the different tasks. I did learn how even in a team we had our own ways of thinking and coding to reach the result.” Feedback from the senior student: “I think it was a successful event just like the year before. […] Those who participated truly enjoyed it and thanked us for getting to have this opportunity to not only experience working in teams but also getting to try more challenging tasks with their knowledge. Most participants were first year students, and we helped some who asked for help to think through the problems in different ways to find the way towards a solution.”

3.3.2 The FoodHack. 13-15th of March 2023, Monday – Wednesday, Krinova[11]

The Food Hack[12] is a 48-hour long innovation competition and food conference for the global food community initiated by Krinova. This year’s Food Hack theme was on Data-Driven Food System[13]. The goal was to explore the opportunities of data as an underutilized tool within the food and agriculture sector. During the first day the participants were invited to three talks: “Tech and data driven food system – what it means and how will it change what we eat and grow”, “How data is transforming agriculture”, and “Helping the consumer care about food”. Thereafter, the participants worked in teams to set up projects boosted by the latest research and experienced mentors, all in the spirit of challenge-driven open innovation.

Admission to Food Hack was free, and all meals to nourish the mind were included from Monday lunch until Wednesday lunch, along with accommodation in dorms (participants were required to bring their own sleeping mat and bedroll). The best hack-teams had the opportunity to win prizes worth 50,000 SEK.

Feedback from one student: “I totally recommend this experience. I think that you only not will gain new knowledge, but also friends. The tutors are amazing. It’s people that inspires you. A new experience, I recommend. Thank you.”

3.3.3 Other events

The University and the Computer Science department offer students additional events throughout the academic year, such as the Future Fair, Research Day at CS, and Career Fair. These events provide students opportunities to kick-start their job

[11] About us - Krinova - Krinova

[12] Food Hack – By Krinova

[13] Food Hack by Krinova 2023 - YouTube

search, establish connections with potential employers, and discover topics for course projects and their degree thesis.

4 RESULTS - SURVEY

The survey shows that the students wish for the university to continue with this module (6.1 in average on a 7-point scale) and that they encounter similar modules in upcoming courses (5.5). The students felt that the module increased their understanding of the subject (5.7) and their perception of their own skills (5.8).

The students reported being motivated and engaged in the course module. After analyzing the survey results, we believe that the reason for the success was the students´ collaboration with companies on real-world tasks, which were inherently engaging and stimulating. In addition to programming the application and utilizing technical knowledge they had acquired throughout their years in the program, the students also acted as consultants, which is a role that many of them will hold in their future careers. This experience helped strengthen the bridge between academic studies and professional work. Two particularly positive outcomes emerged from the course module: one of the actors purchased the prototype app that the students had built, and another actor will be using the prototype app in a research project.

The students not only received grades in Android programming, but also gained knowledge in meeting the customer, maintaining contact with the customer, and acting as consultants, which is a valuable addition to their resumes.

One wish and hope from the teaching staff was that the students would continue with their business projects in subsequent degree projects. One group made this choice and continued developing, investigation and evaluation as a degree thesis, where the company stayed as a secondary supervisor. Their product is currently in use.

5 SUMMARY

Even if an important course *Entrepreneurship and Innovation* was cancelled, it was still possible to incorporate innovation into the programme and provide students with opportunities to enhance their specific academic skills. The examples show how students´ creativity develops through their studies. Nevertheless, the entrepreneurship part is missing from the programme. On the other hand, Krinova offers and helps students an opportunity to do start up their own business.

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A THREE-YEAR ACADEMIC TRACK TOWARDS LITERACY IN SUSTAINABLE DEVELOPMENT - A COMPUTER SCIENCE STUDY PROGRAM CASE

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ABSTRACT

The 3-year Bachelor Programme in Software Development study program at Kristianstad University, Sweden, aims to integrate not only academic competencies and skills in subject courses but also critical thinking skills on how Computer Science can contribute to achieving the sustainable development goals.

Starting from an understanding of the sustainable development goals, students begin a process of designing and implementing applications for some specific goals. Through participation in various activities, students exchange the ideas and perspectives, and are challenged to consider multiple solutions to complex problems.

The students' critical thinking, communicative abilities, and the ability to solve problems both individually as in groups are developed in a clear progression through the education.

This contribution aims to provide an overview of the sustainable development track in the programme, as well as in-depth presentations of some of the courses covered. The main objective of the study was to gather students' perspectives and feedback on the relevance and importance of sustainable development goals in the context of computer science. Students’ views have been evaluated through the survey.

1 INTRODUCTION

This study presents an overview of the sustainable development track within the Software Development program as well as detailed insights into selected courses. Furthermore, students´ perspectives has been conducted and evaluated via a survey.

1.1 Background

The Bachelor Program in Software Development at Kristianstad University, Sweden, is three years programme and is provided for both national (Swedish) and international students. In addition to preparing the students to further studies, the university aims to ensure that they become highly employable. To achieve this goal, several changes in the programme have been implemented during last 10 years.

A main revision of the program was made during 2013-2014 where the Computer Science department has been a member of the CDIO initiative [1] and the program was organized according to the principles of the CDIO initiative. Connections to the industry were achieved in the program through work-based education and "design-build-test" - projects integrated in the subject and project courses. Further changes were made to the program like a clear progression between the courses (e.g., mathematics, programming and software development skills) as well as a progression in academic skills. The implementation of academic skills has been named the *academic track* [2]. It is a systematic development of general competences that create important prerequisites for the development of the scientific approach, which in turn led the students being able to assimilate the subject-specific and reach the degree goal of the education. The academic track thus became a tool that created a clear connection between the general and the subject-specific. In Spring 2018, employees from Computer Science department participated in the university pedagogic course "Teaching for sustainable development". As a result, the subject of “sustainable development” was implemented to the programme in Autumn 2018. Integrating *sustainable development track* in the program was created in similar method as when integrating the *academic track*. New revision of the program was done in 2020 by implementing applied computer science with machine learning and a new course "Research methodology in computer science" to ensure research connection and raise students' scientific attitudes as well as prepare students for the bachelor thesis. The current version of the programme with sustainable track is presented in Section 3.

1.2 Literature Review

The integration of SDGs in computer science education is widely discussed around the world. Nwankwo et al. [3] present six various areas in which CSE (Computer Science Education) and ICT (Information and Communications Technology) are applied for sustainable development. They point the challenges and barriers of the deployment of ICT solutions towards the realization of SDG in higher education and technology development in Nigeria. Gordon [4] describes how the four priority ideas identified by the UK government can be integrated into higher education in computer science. The author gives the examples of the topics that provide opportunities for discussion in the classroom, e.g., the practical and ethical aspects of computer use, consider pros and cons from a societal perspective, security aspects, etc. Argento et al. [5] present how academics representing different disciplines, with specific traditions and characteristics, face the sustainability challenge. The case of University in Sweden illustrates the experiences shared by six colleagues, representing different disciplines (inclusive computer science), engaged in implementing sustainability in their courses and programmes. Mawonde et.al [6] show a case study of the University of South Africa from the distance education perspective. The research revealed several practices that align with SDGs in teaching, research, community engagement and campus operations management. Fisher et.al [7] survey the integration of environmental and societal sustainability into computer science curricula at colleges and universities around the world. They present two integration levels: the course-level, where the computer science courses focus on topics at the intersection of computing and sustainability, and the component-level, where the sustainability themes are introduced as the course components, such as lectures, exercises, and projects. Further, the authors speculate on the future of sustainability-themed computer science education, including curriculum-level integration. Here, they talk about a specialized track with courses within the track differentiated by sustainability topics. They think that computational sustainability majors will be designed around frameworks of evidence-based decision making.

2 METHODOLOGY

2.1 Action Research

Creating and implementation of academic and sustainable development tracks is based on the action research (see Fig. 1) where a group of teachers involved in it discuss and improve the process in regular meetings.

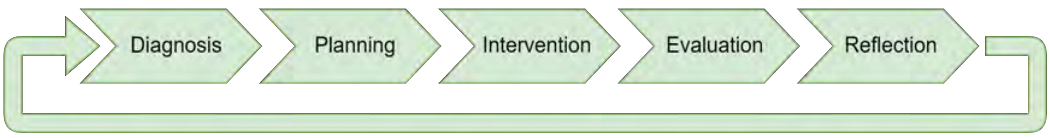

Fig. 1. The cycle of five stages in action reseach [8].

2.2 Survey

The survey was conducted in the Spring term 2023 for 1st year students that already had two courses involved in sustainability track. Students were asked if they were familiar with the subject of SDG (sustainable development goals) before joining the university and their thoughts on SDG in relation to CS (computer science) programme as the amount of information included in these two courses.

3 OVERVIEW OF SUSTAINABLE DEVELOPMENT TRACK

Fig. 2 presents the current version of the programme. The sustainable development track comprises five courses: one introductory course and four project courses. Yellow-marked courses belong already to the track while the green-marked course (a new one in the programme) is under reconstruction to be also applied in the track. Additionally, there is a final course in the program, the bachelor thesis, which allows students to choose a sustainability aspect, although it is optional. However, reflection on societal and ethical aspects in the thesis is mandatory.

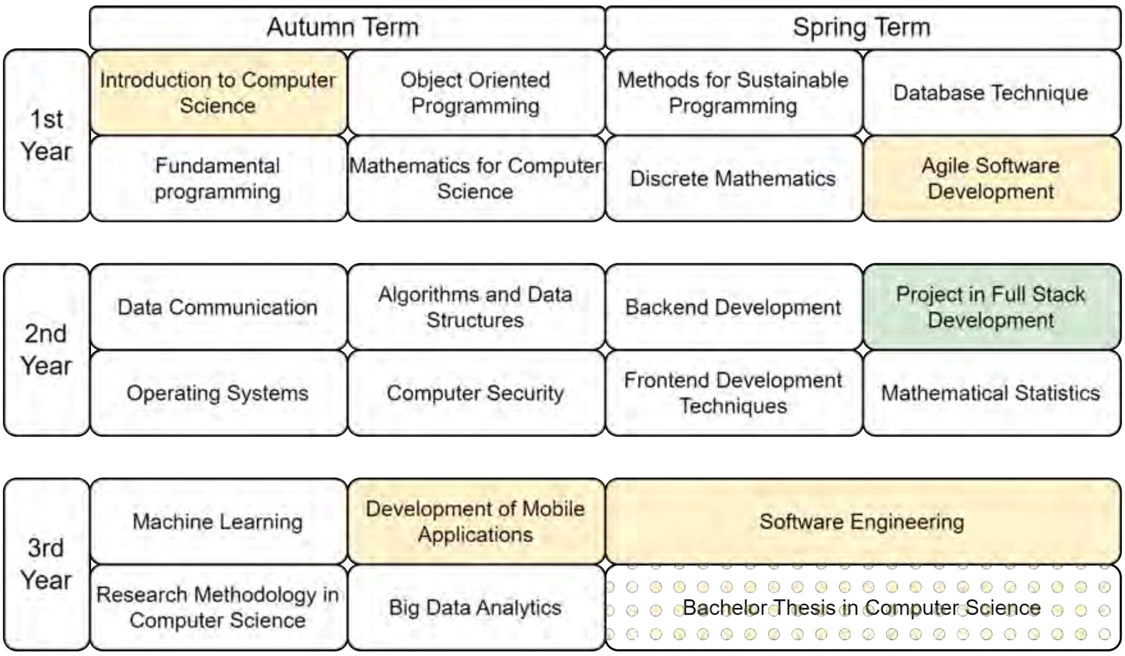

Fig. 2. Bachelor Programme in Software Development, HKR[1]. Marked courses are the parts of the sustainable track.

Table 1 presents an overview of the moments in the courses that include sustainability aspects, along with information about students' work and examinations. It also indicates which learning outcomes are included in the course syllabus that covers the sustainable development track.

[1] Programme syllabus - Bachelor Programme in Software Development - TBSE2 , English | HKR.se

Table 1. Sustainability track in details

Course	Moment in the course	Students` work / examination	Learning outcome(s)
Introduction to Computer Science	Guest lectures: AI in computer science; AI for Sustainability; SDG and Ethical aspects; Literature search; Academic writing; Peer review;	Individual academic report on the subject: “AI in research with a focus on SDG and Ethical Aspects” Practice reviewing each other's reports; Individual presentation and discussion in group during the seminar.	- be able to make simpler assessments with regard to relevant social and ethical aspects (10)
Agile Development Methods	Presentation techniques; Projects.	Group projects with individual written and oral presentations.	- critically examine and reflect on his or her own skills in computer science according to the UN Global Sustainable Development Goals (9)
Project in Full Stack Development	Projects.	Individual written and oral presentation and group project.	Under reconstruction
Development of Mobile Applications	Projects, Imagine workshop	Group projects with individual written and oral presentations.	- discuss the social and ethical issues that may be raised by the use of mobile applications (11) - identify needs for further knowledge and competence for the development of mobile applications (13)
Software Engineering	The project work is in the form of work with company(-ies).	Individual oral presentations and an individual written report.	- demonstrate the ability to make judgements in software projects taking into account relevant scientific, societal and ethical aspects, and demonstrate awareness of ethical aspects of research

			and development work (12)
Bachelor Thesis	An independent project as a specialised study in computer science. (in pairs or individually as determined by the examiner)	Research, written report, oral presentation, written and oral public opposition on another degree project.	- be able to make assessments with regard to relevant scientific, societal and ethical aspects within the field of computer science (6)

4 EXAMPLES OF THE EXAMINATIONS AND PROJECTS FROM SOME COURSES

4.1 Introduction to Computer Science, DA100D

Introduction to Computer Science[2] is the first course that the 1st year Software Development students meet during their education. The course covers a broad knowledge in computer science and equips students with essential academic and scientific skills required for their studies. Additionally, the course provides insight into ethical aspects from a software developer´s perspective and offers a perspective on applied computer science. The students work individually and in groups. Topic of the individual report is “AI in research with a focus on SDG and Ethical Aspects”. Some of the interesting subjects covered in the reports include:

- *Food Waste & AI in SDG efficient production.*
- *AI Implementation in Surgery with an eye on SDGs and ethical considerations.*
- *AI in smart cities. With focus on SDGs and Ethical Aspects.*
- *Role of A.I in Education. Online Teaching and Learning.*
- *The future of humans in an AI-dominated world – with a focus on SDGs and Ethics.*
- *AI´s Fight against world hunger.*
- *Water treatment the environment and the ethical implications.*

It is worth to mention that the report should follow the academic writing style. Students learn how to do literature search, literature study, how to create research questions, how to use the references (tables, figures, literature) and how to write peer review.

4.2 Agile Development Methods, DA116B

The course Agile Development Methods[3] runs as last course in the first year of the programme with purpose to tie together gained knowledge from previous courses, and to develop basic knowledge in carrying out agile software development projects based on the UN Global Sustainable Development Goals.

[2] Course syllabus - Introduction to Computer Science - 7,5 credits - DA100D , English | HKR.se

[3] Course syllabus - Agile Development Methods - 7,5 credits - DA116B , English | HKR.se

The students are preparing for the project through a series of lectures and seminars, where they work both individually and in groups to learn about the product engineering and how to align their product with SDG 3.4, which focus on mental health. As a result of the project, a wide range of desktop applications were developed, including:

- Journaling mood applications with resulting graph to bring to doctor's appointments.
- An app designed to help individuals manage personal stress that is based on earth ecology issues.
- Applications that focus on specific groups of people, such as students or the elderly, to promote their health,
- Applications with training programs for physical activities to promote mental health[4].

During the project, students take on different roles such as scrum masters (team leaders), developers, testers, and support staff. They switch between these roles during the four sprints, which culminate in project meetings where progress is evaluated. The students work both individually and in groups, with the aim of developing a final product that addresses the mental health issue they have chosen. At the final presentation, the students give an oral presentation on the development of the final product and submit a written report.

4.3 Software Engineering, DA330A

The course Software Engineering[5] primarily aims to train students in working in large-scaled projects, and has during the years undergone several improvements, such as, outlined in ([9]). The student group is divided up into *main groups* of about 15 students, each such group is furthermore split into sub-groups of about 3 students with the aim of fulfilling one specific technical goal of the system as a whole, according to Fig. 3.

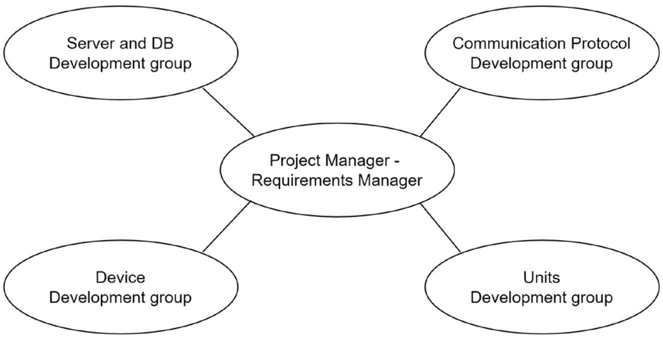

Fig. 3, Student group structure

The main theme of the project under development is to implement a support system for young people with functional disabilities. That approach has its origin in an investigation performed by teachers/researchers of Computer Science at

[4] Myrmidon – appen mot psykisk ohälsa | HKR.se (in Swedish)

[5] Course syllabus - Software Engineering - 15 credits - DA330A , English | HKR.se

Kristianstad University, at a gymnasium for young students with specific needs. The investigation found that the students were dependent on assistance in their living for several banal reasons, such as, turn on lights of lamps, or turn on fans, or pull down blinds to protect against sunshine and warmth in their livings. A consequence of the investigation was an initiation of a Bachelor thesis ([10]) to prototype a smart home-system, where the students should be able to turn on/off lights in their livings.

While that prototype unfortunately did not render further cooperation with the mentioned gymnasium, a consequence was the initiation of a project theme, focusing on Smart Home techniques for young people with functional disabilities. Techniques for supporting such as system is outlined in [11].

The course-students of Software Engineering are aware of that possible stakeholders of the systems are the mentioned gymnasium-students. The course-students should therefore pay respect to the system being supporting the gymnasium-students. As one example, for the course during the spring semester 2023, there is one sub-group that is developing a user interface through an eye-tracker, to support people that are partly paralyzed, and where the eye-tracker is borrowed from an IT-support person at the gymnasium.

The students are furthermore informed about that the system also corresponds to system development to meet SDG 4, on Health and Quality of life. Still, further SDGs that are met by this kind of system are SDG 11 on Sustainable Cities, and SDG 16 on Peace, Justice and Strong Institutions, both addressing the significance in societies being inclusive.

5 RESULTS – SURVEY

37 students participated in the survey. 16 students (43%) were not at all familiar with SDG before joining the University, while 4 students (10%) were a lot familiar with the subject. The overall reaction of applying SDG in CS courses was positive. The answers to the question about the motivation to learn programming through SDG adaptations in CS was very diverse: from 6 (16%) answers “not at all”, through 9 – 12 – 7 in the middle, up to 3 (8%) answers “a lot” (see Fig. 4). The average rating (in scale from 1 to 5) into the integration of SDG in the courses was 77,2%. When asking about the amount of information about SDG covered in particular course, 86% of participants answered: “just enough” for the course “Introduction to Computer Science”, and 89% for the course “Agile Development Methods”. Regarding the relevance of SDG in CS in the future career as software developer, the students were positive giving the average rating of 70,8% (in scale from 1 to 5). Even more positive were they giving the average rating of 81,6% for the question on importance of consideration of ethical and sustainable issues in their work (see Fig. 5). In the open question the students asked about the real-world projects; SDG-focused events such as sustainable tech solutions; collaborations with sustainability organizations. Only one student was very negative about sustainable development, which gives us a thought about some small changes in the first lesson on SDGs and ethical aspects.

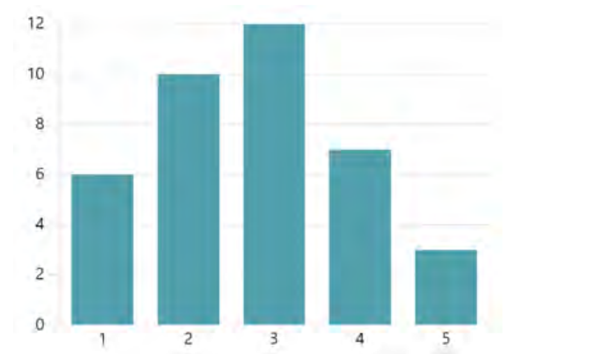

Fig. 4 How much did the SDG subject in CS influence your motivation to learning programming? (1 = not at all, ... 5 = a lot)

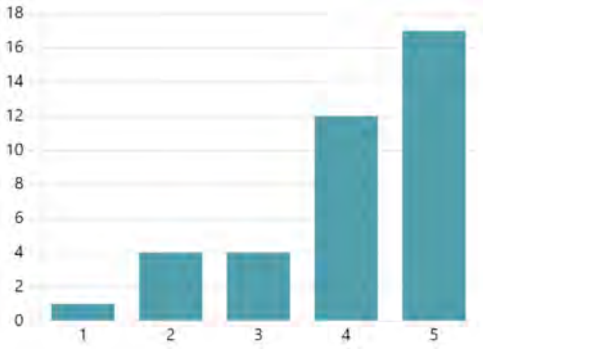

Fig. 5 How important do you think it is for software developers to consider ethical and sustainable issues in their work? (1 = not at all, ... 5 = very important)

6 SUMMARY

Integration of academic and sustainability tracks results, among other things, in high-quality degree theses and more interesting projects with focus on applied computer science. Students write better and can easily connect their reasoning about ethical and sustainable development aspects in the theses and projects. In addition, the students' opinions regarding the implementation of the sustainable development track are quite different, but above all positive. Interesting results were that the students were positive about the importance of the SDG and the consideration of ethical and sustainable issues in their future career as software developers.

Of course, to include sustainability aspects or even academic aspects, something must be skipped in the programme. In our case, we had to exclude some questions/problems that covered pure data science.

The interesting future work would be to ask similar questions to the same students two years after they finished the education.

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THE 'ENGINEERING FIRST YEAR': "*STEP UP"* TO SUCCESS

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Keywords: *Student Experience: Engineering Education Research: Transition: Engineering 1st Year:*

ABSTRACT

The nuanced nature of engineering as a profession is highlighted in a recent statement by the EPC (2023) in response to the UCAS publication *'The Future of Undergraduate Admissions'* (2023). Focusing on the value of Personal Statements within the University Selection System, the EPC asks UCAS to provide more practical information to prospective students about the nature of engineering and what prerequisite qualifications are needed to study engineering. Such clarity is particularly important when considering Engineering Degree Apprentices.

Starting with the research question "*How can the gap between school and university be bridged in engineering education?"* the paper critically discusses a project currently being undertaken by a multi-disciplinary team of colleagues working together to enhance the student experience.

Located in one the UK's largest Engineering Education Departments, the "Step Up" Project analyses the barriers and drivers to engineering education faced by first-year Degree Apprenticeship students from three distinctive engineering and computing science disciplines. This paper represents a small part of a much larger project where

the student experience is being prioritised and high-quality learning and teaching is expected. The paper is built upon the emergent findings of a three focus groups with engineering degree apprentices. Whilst the findings are relevant to all years of study, the recommendations and conclusion highlight the importance of 'getting the first year right' and empowering students to 'step up to success' in university and in work. This evidences a demand for clearer explanations of the knowledge and skills expected of incoming students

1. INTRODUCTION

Building on the corpus of knowledge relating to the first-year engineering student experience (Andrews et al., 2019; Daniels, 2022), this paper sets out to provide a unique insight into engineering degree apprenticeship students' reflections of the main issues impacting their studies as they near the end of their first year of study.

Starting with the research question "*How can the gap between school and university bridged in engineering education?"* the paper discusses the emergent findings of an ongoing pedagogical research project which examines engineering students' perspectives of studying at WMG. The primary objective of the study is to inform and influence academic practice and pedagogy, thus enhancing the student experience from the first year onwards.

2. STUDY APPROACH

The part of the study referred to in this paper provides an insight into the emergent findings of three focus groups were conducted with fulltime degree apprenticeship students in the last academic year. With a sample size of 55 students, focus groups were conducted 'live' online using Miro as a research tool. The data was contemporaneously recorded onto Miro before being transferred into MS Word. Concurrently, contemporaneous notes were made. The decision was taken not to record any demographic details of the students to assure confidentiality. Once the interviews were concluded the data was analysed following phenomenological techniques whereupon it was coded and classified into six distinctive but interlinked themes: Dualistic Education – Balancing Work and Learning: Assessment & Timetabling: Pedagogy & Practice: Academic Integrity: Groupwork: Relevant Engineering Education.

The following paragraphs provide a detailed overview of the conceptual analysis of qualitative findings of the study, providing a distinctive insight into the engineering apprentice student voice. From there the findings are critically discussed before providing a brief overview of ongoing changes to how education is being provided within WMG.

3. THE STUDY FINDINGS

3.1 Dualistic Education: Balancing Work & Learning

One of the key issues to arise out of the study is unique to the 'apprenticeship' programme in that some of the students felt the training received in the workplace did not adequately equip them with the level of knowledge and skills needed to succeed in the classroom:

The WMG course [faculty] assume our line managers / teams will deliver on the technical development … … . When this isn't the case, it leaves students in an awkward predicament of having to try and force a move to a team that suits their career aspirations

From the university perspective the course has been fine. However, from [an employment] perspective the process of ensuring students have enough technical development has not been fully delivered

The resultant misalignment of skills and knowledge between work and study impacted the students in a range of different ways. For many, it resulted in a level of anxiety, something that became evident during the assessments:

[One technical] assignment was very stressful for someone that doesn't have enough experience to create a whole web app. Considering the difficulty of the task the deadline was way too short

The assignment on web development, with little experience was highly stressful. It was covered in the lectures but again expected prior experience at work…

On a more positive note, some students suggested that the gap between work and university was covered by the interdisciplinary nature of the learning and training received:

Modules contain useful information; whilst they do not directly relate to [the type of engineering I am studying], they are useful in a business context.

The course is good as it is a mixture of different engineering skills, IT, and business.

The mixture of 'harder' engineering skills, 'transferable' professional abilities, and 'softer' business competencies is not unique to apprenticeship training. However, the intertwined manner in which each of these is embedded as part of apprenticeship courses, with a mix of different influences, priorities and a need to meet employer expectations means that first year engineering apprentices have to quickly adapt to their dualistic role. The impact on learning that being caught in the middle of work and university has on apprenticeship students is not yet fully understood. One of the areas which the first years in this small study did discuss was, however, assessment – where the delicate balance between what is taught in the classroom and what is learned in the workplace was again identified as an issue.

3.2 Assessment & Timetabling

Assessment was mentioned by all of the students. For some of the first-year students the main issues related to the timing of the assignments and what was taught in the module. Perhaps a causal symptom of low levels of independent learning skills possessed by students as they enter university, the first years perceived assignment briefs to lack clarity; something which they identified as causing undue stress:

Unclear assignment briefs with a lack of clarity get in the way.

Particularly when things are changed close to the deadlines

Assignment briefs and ambiguous briefs make the assignments more stressful than they need to be

It is not unusual for first year students to bemoan the fact that they are not taught all of the course content in the classroom. Although for apprenticeship students the issue isn't simply about a lack of independent learning skills, but instead relates back to the first theme discussed in this paper, differing expectations of faculty and students and a misalignment between what is taught in the classroom and learned in the workplace.

3.3 Pedagogical Approaches in Engineering Education

The study took place after the pandemic whereby the majority of students interviewed had spent at least 18 months in lockdown learning at home and online. When the interviews took place students were divided more or less equally when it came to whether they preferred online or face-to-face teaching. Some students asked for a choice in whether they should attend a lecture in person or not:

It should be a choice as to go on site for face-to-face lectures or not. We should be told what the lecture is about in advance so we can make an informed decision

I'd like the option to study at home rather than have to be in person

3.4 Academic Integrity

Like the majority of first-year students many of the apprentices struggled with referencing and academic writing, particularly at the beginning of their course. One student mentioned the penalties associated with poor academic practice:

I have been marked down for incorrect referencing, despite having my referencing checked by someone qualified and being told it was correct.

Others' indicated that they felt it was their lecturers responsibility to provide them with a list of academic sources, which suggests a lack of preparedness for independent study:

The reference list at the end of the slides is often wrong. They're the same in every session in the module [ ]. Sometimes the references don't relate to the content of the slides

Adding a citation on every slide would be super useful. Often, we need to use information from the slides in our assignments and a topic can be too generic to google.

3.5 Groupwork

Like the majority of students, engineering apprentices report negative experiences around working in a group:

Group projects don't tend to work as there will always be 50% of the group who won't work and who will get away with this. There's no way to rectify this. The fix is individual assignments.

Randomised groups for some coursework where the lectures decide the groups. This causes problems when people have different work ethics.

Group projects are more irritating than beneficial, they lead to conflict and greatly affect wellbeing as people think they can get away without working. This is something that has greatly impacted my opinion of the course.

The most concerning remark about groupwork came from a student who questioned the academic validity of this type of assessment:

Group projects seem to be giving lecturers less to mark – doesn't benefit us as students really especially when they are randomised - being with people who don't work as hard is so frustrating when you care about your grades

Conversely, two students suggested that for them, group working was a positive experience: '

Groups allocated by the lecturer are useful and give everybody a fair chance (i.e., no higher chance of being with a 'better' group)

Group projects keep me going when I've been in a group with people who want to get the same grade as me

3.6 Relevant Engineering Education

As they neared the end of their first year, the students commented about the gap between university and work with one student indicated that the issue was with who, from the employer, contributed to the design of the curriculum:

The course is clearly designed by / with [the employers] – but it seems to be designed by high level managers, not the low-level managers who actually, interface without roles. It would be useful to ask their opinion of what we need to know and for modules to contain what we need to be taught. Low level managers actually know what our job is.

4. DISCUSSION

This paper has briefly looked at the experiences and perceptions of three cohorts of students studying on one of a number of engineering degree apprenticeships at WMG, University of Warwick. For first year students one of the key issues related to differences in what faculty members believe they are trained to do in the workplace and the knowledge and skills they actually have when they arrive in the classroom for a period of block learning. Previous studies in this area are difficult to find although there exists some literature around a perceived 'knowledge and skills expectations gap' in Biological Sciences which found a gap in student knowledge and lecturer expectations indicative of discipline-specific knowledge and knowhow (Jones et.al., 2018) although this study related to general students and pre-university knowledge.

In considering the ‘expectations and reality’ gap raised in this study, it may be postulated that such inconsistencies may be indicative of differing entry requirements for students enrolled on apprenticeship as opposed to traditional undergraduate programmes (Sole et al., 2021). In many universities, apprenticeship students do not have traditional entry qualifications, although in the case of the cohorts sampled, on the whole this is not the case. The entrance standards are similar for apprentices and traditional students within the university, although in some cases apprentices are required to possess higher grades. This means that disparities in *a priori knowledge* on admission to university should have been dealt with early in the course (Scott & Willison, 2021), meaning that problems were more likely to be indicative of different expectations of learning in the workplace

Student dissatisfaction with assessment is recorded in the literature and engineering is no exception (Oti et al., 2021); hence, it is not surprising that many students commented about how they are assessed. What is different for degree apprenticeship students is that they can be assessed on what is learned at university and in the workplace. This in itself may be problematic, apprentices on the same course may be from different employers; indeed, even those from the larger companies do not necessarily receive the same training as others working in their organisation. For this group of students, the need for carefully design assessment is of paramount importance. However, whilst the need for anonymous marking is generally accepted to be vital in promoting an equitable and fair learning environment (Giray, 2021) this may not be the case when dealing with apprenticeship students. What is needed instead is an approach to assessment and marking that is carefully designed and managed to ensure a lack of bias and high levels of integrity.

The need to nurture a culture of independent learning across the undergraduate student body, particularly in the first year of study, is recognised in the literature. This is particularly important when considering first year apprenticeship students. Research in this area is particularly spartan, with little or no previous papers considering how today’s apprentices become independent learners whilst gaining a new identity at work.

That the student participants had mostly negative views about working in groups is not unusual. Problems with groupwork amongst the traditional student body have been long discussed, although again literature pertaining to the engineering apprentice student experience is rare. Moreover, whilst moves towards blended and hybrid pedagogic approaches came to the fore during the pandemic (Petchamé et al., 2021) the impact of these approaches on first year degree apprentices remains unknown.

5. SCHOLARSHIP IN ACTION: THE DEVELOPMENT & INTRODUCTION OF EVIDENCE BASED CHANGE

This paper can necessarily only begin to touch upon the change occurring within WMG as senior management strive to induce a co-created academic and scholarly environment where student experience is prioritised and high quality learning a ‘given’.

The six themes highlighted in the findings are now briefly contextualised within the change occurring in learning and teaching.

5.1 Dualistic Education – Balancing Work and Learning:

One of the most important findings to emerge out of the study thus far relates to how little is known about the experiences of degree apprentices in general and engineering apprentices in particular. Whilst the study begins to address this gap, there is much to learn, perhaps the most important of which relates to differing expectations of what role universities and employers play in educating apprentices. The emergent findings indicate there is a clear need for continued and continual discussion between all stakeholders involved in providing apprenticeship training. Such discussion is now forming part of, and informing, transformational change; with apprentice tutors playing a key role in bridging the employer-university gap.

5.2 Assessment & Timetabling:

The main finding relating to assessment reflected problems engineering degree apprentices seem to have in developing as independent learners. To support this WMG is putting into place a ‘Student Hub’. This will be a ‘safe space’ where all aspects of the student experience can come together and students are provided with individual support and guidance in areas such as academic writing, time management as well as wellbeing support.

5.3 Pedagogy & Practice:

Reflective of ongoing advances in technology, unprecedented numbers of people now work from home. Engineering degree apprentice students find themselves in a ‘brave new world’ following the Covid19 Pandemic, it is therefore unsurprising that views about whether learning should be online, or in-person vary so much. Yet it is clear from this study is that students want autonomy to choose whether they work from home or at the campus. WMG has put in place significant measures to make hybrid learning a reality. Lectures are recorded, or pre-recorded and use of technology proactive designed into the curriculum. There are many opportunities emerging as technology advances in the field of learning and teaching, hence there is much work to do in this area, but, in actively listening to the student voice, advances are being made.

5.4 Academic Integrity:

First-year students seem to traditionally struggle with academic practice and integrity. To address this a cohort-wide module of study, professional and analytical skills has been developed specifically for the undergraduate student body. Students are able to individually access help, guidance and support in any multiple areas of academic practice in a flexible and blended manner.

5.5 Groupwork

Groupwork is part of university life. To promote group cohesion amongst undergraduates, a number of actions have been taken including providing proactive compulsory training compulsory for one cohort of students. In future, ‘working in teams’ will be covered in the student induction. Other pedagogic actions include providing training in the area of course and programme design.

Colleagues are actively encouraged to adopt constructive alignment, and quality assurance checks in place to make sure that when groupwork is used it has a solid academic grounding and justification.

5.6 Relevant Engineering Education

Student confusion in respect of the relevance of their education to their apprentice role has resulted in a more open approach to curriculum design. Students and employers both have a voice and whilst employers co-construct the degree apprenticeship programmes, plans are underway to include students in future design activities. First year students are given plenty of opportunity to ask questions about the curriculum content and context, not only during Induction but as the course unfolds. Likewise, apprentice tutors work hard with individual students to make sure that linkages between learning and work are made irrespective of whether the student is sponsored by a Small-Medium-Enterprise or multi-national engineering company.

6. CONCLUSION

This short paper represents a small part of a large, ongoing scholarship project aimed at enhancing the engineering student experience. The appointment of a Director for Student Experience and a dedicated ‘Student Experience Budget’ shows the commitment of the Department to enhancing the student learning journey. The ongoing change is beginning to pay dividends and efforts to promote a sense of belonging and identity amongst our students and staff have resulted in the emergence of a proactive and cohesive learning community. There is much work to do, but with a committed team of staff and students, working together, advances are being and will continue to be made. In conclusion, whilst the findings of this study are relevant across all undergraduate and postgraduate cohorts, the need to ‘get the first year right’ is of particular importance when it comes to engineering degree apprentices. WMG is currently undergoing a period of significant change. The team who’ve contributed to this paper are an important part of this change, working together to empower students to enable them to ‘step up to success’ both in the classroom and in the workplace.

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TEACHING ETHICS AS A PRACTICAL EXERCISE IN REFLECTION IN A PROJECT-BASED ENGINEERING COURSE

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ABSTRACT

The implementation of ethics in engineering courses often faces several intertwined problems. For example, there is widespread moral relativism, ethics is often confused with moralism on the one hand and with pro-contra discussions on the other, there are difficulties with the degree of abstraction being too high, or ethics is relativised as one method for decision-making among many others. Furthermore, in many cases, ethics is suspected of being artificially introduced into engineering.
In the context of a project-based course at a German university, we took up these challenges and developed an innovative teaching format whose focus is not on theories and methods. Instead, we implemented ethics education as a practical

exercise of reflection. Based on situations in students' project life, we engaged in open conversations addressing aspects of their practice that tend to be overlooked under conventional conditions: boundary conditions of their engineering actions, preconditions of their judgements, and criteria for justifying their decisions. Instead of reacting to problems reflexively, and thus blindly accepting them, we wanted to enable students to examine problems critically. In this way, we aimed to enable the students to adopt a (reasonable and therefore) responsible attitude toward their actions and their boundary conditions.

In our contribution, we first discuss the preconditions: the project-based four-month full-time course with an industrial partner. Second, we explain and justify our philosophical approach. Third, we describe the implementation of our approach followed by the evaluation. Finally, we conclude our findings and outline next steps.

1 INTRODUCTION

1.1 Motivation

In their paper on phronesis and the role of values, Frigo et al. (2021) highlighted the need for teaching ethics in engineering and discussed a potential application. However, the responsibility that engineers bear in their professional activities has not been reflected widely as part of engineering education, especially at German Universities (Frigo et al. 2021). The central role of engineers in finding technological solutions to fundamental societal problems (Frigo et al. 2021) thus leads to the necessity of teaching ethics in engineering education. Courses that are more practically oriented can provide a particular purposeful opportunity (Frigo et al. 2021). Based on the preliminary considerations of Frigo et. al. (2021), this practice paper develops and implements a detailed concept for teaching ethics in engineering education at a German university and reflects on its evolution over two years.

1.2 Our mission

Within the framework of a German excellence promotion program, we pursue the goal of building reflective competence among students in ethical and social issues. The overarching approach chosen can be described as teaching “ethical literacy” and is characterized by teaching ethical-reflective competence instead of principles and theories. For this purpose, our interdisciplinary team led by philosophers offer a variety of services, including online courses, co-teaching events, and challenges to realize the above-mentioned goal. The course presented in this article is part of this offering.

1.3 The project-based engineering course

In the course IP - Integrated Product Development in which we are implementing our pilot project, a selection of master’s students from the fields of mechanical engineering, industrial engineering, and mechatronics work in teams through a 4-month product development process from strategic foresight to prototype construction. The problem definition for the development project is provided by an industry partner. During the project the students independently develop product profiles, alternative solutions, and prototypes, which they present to the industry partner and invited guests from research and industry at a final event (Albers et al. 2018). As the main stakeholder for the solutions developed by the students, the industry partner is pivotal to the practical learning environment.

The coordination of the development process and the methodological coaching of the students is carried out by scientific staff of the IPEK - Institute of Product Engineering, who are themselves mechanical engineers. Decisions as well as feedback on the intermediate results takes place through the industry partner at multiple milestones. Between these milestones the students independently decide how they spend their time and balance efforts. The course can be associated with challenge-based and project-based learning methods (c.f. Membrillo-Hernández et al. 2019). Fundamental to the course is the understanding of product development according to the Karlsruhe School of Product Development (KaSPro) specifically in relation to demand- and benefit-driven innovation (Albers, Düser and Burkhardt 2006).

Due to the students' freedom of choice, its implications, and the courses’ nature as preparatory for the students' entry into work (as part of the master’s degree), the course offers a well-suited opportunity for our mission and the obligation to address responsibility in engineering education. While there have already been preliminary conceptual considerations, the development of a consistent teaching concept and its implementation remained open. Therefore, this contribution justifies and proposes a detailed concept for teaching ethics as a practice while acknowledging the complexity of engineering education. Moreover, the concept is implemented and evaluated with two cohorts in the winter terms 2021/22 and 2022/23.

2 TEACHING ETHICS AS A PRACTICAL EXERCISE IN REFLECTION

In both teaching and being taught theoretical content, we are accustomed to viewing this content as retrievable pieces of knowledge. Examples include the fundamentals of engineering mechanics, mathematical methods, functional principles of machine elements and many more. In engineering courses, we teach many such things, which are undeniably important. Alongside this kind of knowledge, we also teach and learn methods which are instructions or procedures that help us to contribute to a solution of a given (technical) problem under certain circumstances. A good engineer is characterised not least by the fact that they are able to choose the most appropriate method for the problem from their arsenal of methods. In this way an engineer demonstrates the competence to understand the problem as well as the function and mode of action of the chosen method to be able to apply it purposefully. The interaction of theoretical knowledge, knowledge of methods, and the understanding of problems makes engineering a lively activity—especially when engineers become creative and have to work out new ways of solving unprecedented problems. This lively activity can be called "practical skills".

Whoever wants to teach knowledge, methods, or even practical skills is faced with the question of the best way to do this. Under certain circumstances, one must also ask oneself the definition of "best" here. Of course, we also had to ask ourselves what it could mean to teach what we wanted to teach.

We knew we wanted to enable students to act in a responsible way. Assuming what it means to act responsibly would be a kind of theoretical knowledge, we could have taught our students a theory of responsibility and tested this knowledge in an exam. While this might be possible, the concept of responsible action does not describe knowledge about the world or about how people are but addresses their actions. Having an idea of what it means to act responsibly enables one to identify and evaluate one's own actions or those of others as such actions accordingly. But then one does not have theoretical knowledge, but a norm for a way of acting. And with norms, you have to justify why they should do in this way. To understand responsibility as a kind of theoretical knowledge seems at least problematic.

What would it mean instead to understand responsible action as a method? If so, we could have told students to follow a procedure and their actions would henceforth be responsible. But we did not want to teach one method among other methods, or even the most important method of all other methods. We wanted students to be able to make responsible use of their arsenal of methods in case of doubt. The ability that we wanted to make accessible to our students concerns the *how* of their actions–not just the *what*–and it seemed to us that whatever was connected to that ability lay to be beyond the choice of method. Because this ability is neither theoretical knowledge nor a method, but is expressed in people's actions, we ultimately had to understand it as a kind of practical skill–namely the practical skill to act responsibly. Approaching our concept of responsibility in this way raised another question: how must we understand our mission based on this understanding of responsibility so that we can seek options for its realisation that do justice to the matter of responsibility?

However as often happens in philosophical practice, the questions are initially unsettling: instead of providing support and finally a solution, they seem unnecessarily complicated and endless. Couldn't we have simply defined responsibility somehow and then taught this definition to the students? But wouldn't responsibility then have remained merely a piece of theoretical knowledge again instead of becoming a practical skill? And would it have been responsible at all to simply define the concept of responsibility in that way or to adopt it from others without reflection? What are the criteria for us to act appropriately in each case?

Therefore, the question of how we would understand responsibility not only affected what we wanted to teach, but also our own actions. As we have said, the easiest approach would have been to simply presuppose a given understanding of responsibility and tell the students how to act in the future. Then we would have solved the problem that we need a concept of responsibility. But we would have left the context unconsidered and thus already accepted the conditions under which the perceived problem appears as a problem. Consequently, just because the problem-solving mode is possible does not mean it is appropriate.

When we are responsible for teaching others what it means to act responsibly and why they should act that way, then we firstly have to be able to justify why this is a good concept of responsibility. And secondly, if we don't want to get tangled up in contradictions, we must do justice to our responsibility both in the rationale for it and in the way we want to convey it. This means that whatever concept of responsibility we choose, it reflects on us and on our actions. When we think about how to teach responsibility, we have to look at what we do while thinking about it.

What did we do? First, we wanted to gain a proper understanding of it. We did not accept the supposedly obvious problem and set out to find a solution for it. We refused, in this context, to presuppose an arbitrary understanding of responsibility or to recognise an understanding of responsibility merely because it comes from a potential or supposed authority. Secondly, we did all this with a view to asking how we must act to do justice to the matter. Thus, thirdly, we have understood and reflected on ourselves as the cause of our actions. What would it mean if that were already a form of responsible action? According to this view, a person acts responsibly who relates to their own actions in a certain way: They ask themselves *what* they do, *why* they do it and *how* they do it (in what way and under what conditions). Since they understand themselves as the cause of their actions, they also understand that they can relate to them in reflecting on these issues. This means that they can and must also ask themselves whether they should do what they do or what they should do for what reasons.

We wanted to enable the students to look at their own actions in this way as well. They were to be enabled to make the presuppositions of their own actions transparent to themselves. We considered that if the students could learn to do this, they would in future act less automatically in the way they have done it in the past, or do what they do less arbitrarily, or not act merely out of obedience.

But with this it was also clear: if we want to give students the opportunity to make decisions and to act accordingly in a responsible way or more responsibly than they may have done in the past, then we cannot treat them like automatons that one feeds with input. Instead, we must see them as acting subjects who ought to be able to arrive at independent judgements, and whom we must therefore also allow to contradict us. Not in an arbitrary way, of course, but we would be good teachers if we were exemplary in what we try to teach. In other words: teaching in this respect and in our context would have to be a practical exercise in reflection for *both* sides—for the teachers as well as for the learners. But since no one can be forced to reflect, there would also be no guarantee that the impartation would succeed. The possibility of

failure still lies in the nature of things. It is in our hands to provide the possibilities to be able to relate to one's own actions in a reflective way. But as with any other opportunities, there is always the option of refusing this offer. Since taking responsibility is something that can only be done by the actor, we have no choice but to rely on the voluntary understanding and acceptance of the students.
With this, we have finally reflected on one last aspect of responsibility as it arises in our context: the scope and limits of our responsibility. In conclusion, when talking to the students about responsible action, we would have to enable them to:

- understand themselves as the cause of their actions,
- therefore ask themselves what they do, how they do it and why they do it,
- therefore reflect on what the specific conditions of their actions are and what, against this background, falls reasonably within their scope of action for which they are responsible, and
- finally be able to reflect on whether they should do something—and what they should do as well as why.

At least here, responsible action thus shows itself as a kind of justice: those who act responsibly (under conditions) try to do justice to certain aspects of their actions, especially being the cause of their actions. So, what we would have to teach as a practical skill would be a particular attitude towards one's own doing. And because this attitude positions one's own actions under a principle—in our case under the principle of responsibility—it can be referred to as an "ethos". In our understanding responsibility starts here. But whether it also ends here is another question.

3 RESULTS

3.1 Implementation

As we have seen, the essential part of our teaching should be to enable students to develop an attitude towards one's own doing. The core of our teaching must therefore be to offer them opportunities in which they can relate to themselves and practice reflective competence. To enable this reflection, we have set ourselves three goals (cf. Fig. 1): 1) we would need to "open doors" to a new attitude for the students; 2) we would have to enable students to "open doors" to reflection for themselves; and 3) we would have to show the students connections between their attitude and the work they do on their project.
We call the overall concept "ethical accompanying reflection". The concept consists of four distinct but connected components: a 90-minute ethics lecture, a 120-minute ethics workshop, a series of reflection sessions and a lecture series. The first three components were delivered by trained philosophers, mentors from the Institute of Philosophy. The lecture series component was realized by inviting "practitioners" from the industry.
The **ethics lecture** represents the students' first systematic encounter with questions of ethical responsibility within the framework of the course. It is structured more traditionally as a lecture and is intended to convey the relevance of dealing with this topic in this framework. We expect the ethics lecture to contribute to goals 1 and 3 we mentioned. In the current version of the lecture, the necessity to deal with one's own responsibility is derived and justified from the self-image of engineering practice: since they experience and understand themselves as acting and shaping, the necessity of responsibility can also be addressed based on the experience of this freedom now.
The **ethics workshop** is also a plenary event and is intended to create a bridge between the ethics lecture and the reflection sessions. We regarded the workshop as

serving our goals 1 and 2. Accordingly, it differs from the ethics lecture in that the students should already be actively involved in discussions–in accordance with our approach–not with the aim of developing solutions to problems, but rather in such a way that their answers can themselves be made the subject of joint analysis and discussion. In this way, the workshop interrogates the students' "natural" judgements and addresses the basis for their justification. In the current version, we devote most of the workshop to discussing a trade-off example: confronted with the question of how the AI of an autonomously driving car should "decide" in a certain dangerous situation, we divide the students into teams. They are asked to discuss the basis on which they would make and justify their judgement under the guidance of their philosophy mentor. The results of the team discussions are shared with everyone in the final plenary again. The aim of the exercise was not to arrive at a definitive judgement on a seemingly harmless example, which presumably everyone would have an opinion about, but to ask what the students presuppose for their judgement in each case, and in turn to make this presupposition the object of consideration.

As the most appropriate way to engage with the students and thereby create the space for reflection, we decided to have multiple small group meetings with the teams, called **reflection sessions**. They form the core of our accompanying reflection: each student team is assigned a philosophy mentor who meets with the team for four 90-minute sessions over a period of two months. The themes of these sessions are not determined by the philosophy mentors, and no pre-determined learning objective is issued for any of the sessions. In these sessions, it is very important that the philosophy mentors engage with the students and react to the situation they are in. Of course, the discussion is about the status of the development projects themselves. But in this discussion, aspects of responsible action are worked out–not following a theory, but through the philosophy mentors engaging with the situation in a new way, i.e., with the object itself. Here we ask which criteria the students have used for problem identification and innovation potential, and why these criteria were used instead of others, for example. We ask about their reasons for ultimately choosing one product idea for implementation and why these are good reasons. We ask about the fundamental values that they are acting on in the project and why they think that they should do so. We further ask what they see themselves as responsible for and what they don't, as well as the reasons for that. In this way, the students are confronted with aspects of their judgements and actions that are taken for granted and otherwise rather non-objective for them. However, this does not happen artificially and with external standards; rather, it emerges from the project situation and is based on the criteria and standards expressed by the students themselves. In this way, we enable ourselves to discuss not just what should be done, how it should be done, and for what reasons, but also where the responsibilities and the limits of our own responsibility lie. The reflection sessions are therefore suited to each of our three goals.

As a final component, we organized a **lecture series** as a complementary format. In this series, we invited five guest speakers to talk about situations in their professional practice in which they were confronted with questions of responsibility according to their own assessment and the challenges their faced. The aim was not to tell success stories. Rather, these presentations were intended to demonstrate the many different levels on which such questions of responsibility can arise, which cannot be dealt with using a standard procedure. To ensure a certain uniform structure in the lectures and an orientation towards our need for knowledge, we drafted a catalogue of guiding questions. In addition, we held preliminary talks with all the speakers to agree on the direction of the presentation and discuss a first draft. The lectures themselves did not refer to each other, but we organized them in a way that the levels of reflection changed from lecture to lecture. In our view, this was well-suited to helping achieve goals 1 and 3.

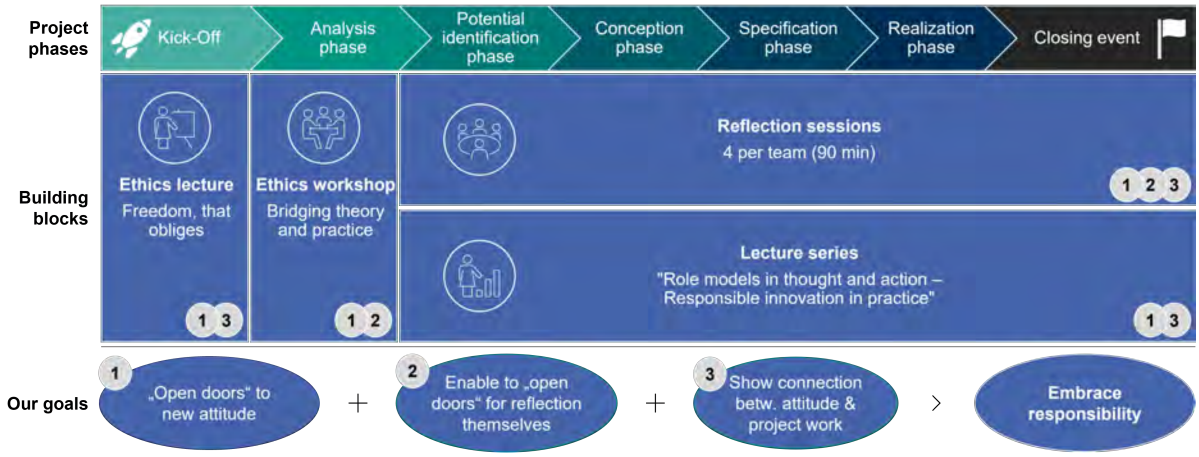

Fig. 1: Project phases of the course and implementation of the teaching approach

3.2 Evaluation and Discussion

Of course, we asked ourselves about possibilities for determining whether our accompanying reflection has an impact and, if so, what kind.

A possible impact can be analytically differentiated according to the "places" in which it finds expression. It would be desirable to look for an impact in the results of the students' work. We do not know any method to determine this, since it is impossible to determine the results that the students would have arrived at without the accompanying reflection. Since we do not primarily want to impart knowledge, but rather to enable an attitude, which only shows itself in practice, one would have to ascertain the status of the students' attitudes beforehand. And even so, it is uncertain whether they subsequently act due to an "ethos" or only display a socially desirable behaviour. A possible approach is to ask which aspects of their decisions the students themselves would attribute to the accompanying reflection. However, such an effect would only be an indirect phenomenon, which could also only be determined unreliably by discourse, even if the discursive discussion would be interesting.

This discursive element does, however, point to a second "place" where we can evaluate a possible impact, namely the reactions to and judgements about the accompanying reflection by the people involved. For this, we perceived various evaluation possibilities, some of which were quite elaborate (cf. Table 1).

Table 1. Applied evaluation methods.

	Students	Mentors	Externals
Cohort 1	Anonymous questionnaire	Interim reflection meeting with engineering mentors and philosophy mentors	Sociological accompanying study
		Follow-up meetings with engineering mentors and philosophy mentors	
Cohort 2	Anonymous questionnaire	Interim reflection meeting with philosophy mentors	/
		Follow-up meetings with engineering mentors and philosophy mentors	

		Documentation assignment for philosophy mentors	

In both cohorts, we were not able to derive any tangible improvements to the course from the questionnaire, but we were able to confirm the fundamentally positive reception by the students. However, participation in the survey was limited to 40 percent in each cohort. In addition, students' responses were very diverse in individual aspects of the course, but students did not make use of the opportunity to give their reasons. For us, it therefore remains unclear according to which criteria the students judged and whether these are appropriate. Certainly, the fact that the reasons for their responses were mostly omitted that the students did not consider the possibility for a discursive discussion with us to be necessary–whatever their reasons may have been.
The interim reflection meetings and follow-up meetings with the mentors of the first cohort were rather unsystematic and most closely resembled an exchange of experience. A shared finding was the fact that the students had difficulties understanding the purpose of the accompanying reflection and had expectations that we could not possibly fulfil because they did not correspond to our mandate. We therefore brought to the second cohort the insight of needing to manage expectations better and we clearly stated what our mandate is not in as many places as possible. This insight flowed into the conceptual redesign of the ethics lecture and the ethics workshop as well, both of which aim now to better reflect what constitutes the core of the accompanying reflection in their content and procedure.
For the first cohort, we also accepted the services of sociological accompanying studies. A research team from the university was commissioned to use a qualitative study to investigate the effects and impacts of our teaching offer for the students and to develop possible suggestions for improvement. Data was collected through participant observations of our teaching practice, semi-structured interviews with students and philosophy mentors, as well as text analyses of the milestone presentations. The 29-page study, which is not publicly available, concluded overall and in principle that, on the one hand, "the integration of ethical and responsibility-related reflective content in the course [...] was valuable according to all participating students, engineering and philosophy mentors" (Hausstein 2022). It also stated that our project required a considerable amount of human and temporal resources, but with external conditions being beyond our control, was not always able to meet this requirement. On the other hand, several other results showed that this study was based on a different understanding of our role than what we discussed in section 2 above. The study thus has only limited usefulness for us. If it were to be repeated, we would have to engage with our colleagues in a much greater effort to reach a common understanding of what we aspire to.
In contrast, a real novelty was introduced with the documentation of the reflection sessions by the philosophy mentors in the second cohort. We of course asked ourselves whether we had given ourselves a meaningful work assignment with this format in the first place, whether the considered approach made sense, and what we might have to change in the objectives. Therefore, the documentation by the philosophy mentors is a kind of reflective self-evaluation, which should have the side effect of individual reflective follow-up by the respective mentors. In six questions, each with sub-questions, the documentation asks, among other things, about the topics discussed, the ethical issues discussed, the particularly noteworthy interventions on the part of the students in terms of content and performance, and the approaches used by the mentors, as well as what the mentors would do differently in

retrospect to their own approach. As a result, we have a large amount of data that both allows for a comparison between the individual teams for each session and would make a possible development over all reflection sessions visible for each team (which is currently being evaluated for the second cohort). Of course, the same applies to the philosophy mentors' assessments of their own approach.

4 SUMMARY AND ACKNOWLEDGMENTS

We have shown that our entire teaching concept is designed to provide opportunities for reflection on one’s own practice of judgement and its presuppositions in order to potentially adopt a new attitude towards one’s own decisions and their foundations. Our primary goal is not to impart knowledge that can be tested.

The evaluations completed thus far and those currently ongoing indicated, that we set high aspirations for ourselves and require a high degree of willingness of the students to engage with us as well as to spend enough time engaging with the topic of responsible action in addition to everything else they must do for their projects. This willingness is not always present or evident. Some students tend to dogmatically determine for themselves and everyone else what is right and what is wrong and use rhetorical persuasion to get their way. These students do not seem to be interested in conversation. But they are the same students who cause unproductive conflicts in other team contexts in the project. Consequently, the reflection sessions then help other team members to see the real problem and its logical causes. They can then limit such destructive actors with reference to the common team purpose–again encouraged by the reflection sessions. In addition, there are those students whose thinking–for whatever reason–cannot break out of the problem-solving mode during the mentoring period, and who thus block their path to reflection. Our outreach is most promising with those students who are open to learning something new. They curiously accept our offer to try something different from what they are used to and to take a distanced view of their own presuppositions and supposedly self-evident facts. All students demonstrate that they make value judgements and have an idea of what is right and wrong. But not all of them are therefore ready to talk about it. Not even when they make value judgements in a professional context and their attention is drawn to it. But since we are always dealing with teams and groups, the actual addressees of such disputes are then the other participants, even if they are only observing. In all this, we must concede that with the at least perceived high pressure to succeed in their project, some students simply do not have the necessary time to acquire such a self-critical attitude.

As mentioned above, it is difficult or impossible to reliably demonstrate a direct impact of the accompanying reflection in the final products of the students’ projects. And it is equally impossible to verify a virtuous attitude. However, since we have the discursive option at our disposal, through which we can indirectly determine whether someone is performing in a responsible way, from our point of view the next step is to find an answer to the question of which approaches are suitable for obtaining feedback from students in which they can prove themselves to be the mature, responsible persons we are trying to address them as.

However, our own standards also show that we ourselves must not succumb to the pressure of problem-solving thinking. We must set aside our own reflexes and be reflective in our exchange with students and in dealing with their problems and our own. Admittedly, in what we are trying to teach, there is no guarantee that the teaching will succeed. But the least we have to do is to measure our own actions against these common standards of responsible action and assess whether we are living up to them.

In turn, this seems to us to be a central prerequisite for a possible transfer of our attempt to other contexts. And this insight is as old as the philosophical doctrine of virtue itself: whoever wants to convey a virtuous attitude must act as a role model in this matter. They must demonstrate in practice what it means to act virtuously, and they must provide the framework conditions in which it is possible to learn to act virtuously. In our case, these conditions comprise the hopefully exemplary behaviour of the philosophy mentors in the reflection sessions, the reports in the series of lectures by the practitioners, and, we hope, the overall conception of our accompanying reflection. Whether our ethics lecture, ethics workshop, and our style of reflection sessions make sense in other contexts depends on what exactly is to be taught. In our opinion it makes sense if you want to create an opportunity to show what responsible action can mean and if you understand responsibility in the way we have made explicit in section 2. However, in our opinion the internal reflective consistency of content and practice is what matters in any case.

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THE ART OF REPAIRING - OR HOW TO TEACH ENGINEERING STUDENTS SUSTAINABLE DESIGN PRINCIPLES

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ABSTRACT

Project-based learning bridges the gap between theoretical training and practical applications. The motivation of students to participate is increased especially by working out real-life problems. To provide this kind of practical learning experience, we are establishing a repair project for broken, otherwise discarded, lab equipment. It will not only help to reduce waste and save money by repairing research equipment, but will also encourage interdisciplinary collaboration and innovation. Providing a space to learn about the underlying functional properties of various often highly specialized lab instruments, students identify malfunctions, deepen understanding of vulnerable designs, and discuss and perform strategies for repairing them under guidance, while collecting credit points. Through gaining a deep understanding of how these instruments work, students may even invent new strategies to realize similar tasks or add new features. This project builds on the findings from a 2021 pilot study. We discovered that by offering a repair project, students were able to gain a deeper understanding of theoretical concepts, improve their self-confidence as well as their motivation in learning, and increase their awareness of sustainable design. In the following, we are presenting the transformation of the pilot study into a current course concept. With weekly mini-evaluations we are monitoring students' learning success towards their learning goals and share the results.

1 INTRODUCTION

1.1 Motivation

"Addressing the complexity of sustainability requires innovative practices for teaching and learning, leading to new methodologies that aim to develop the broad sets of competencies required from the students." (Kunrath and Beliatis 2022)

The 12th goal of the Global Goals Agenda for Sustainable Development ("United Nations Development Programme" n.d.) demands responsible consumption and production. In this context, in addition to an improved process cycle and the reuse of components, the repair and preservation of existing equipment is an essential sustainability goal. These goals are gradually being enshrined in EU legislation. For this reason, the European Commission presented a proposal on the "Right to Repair" - consumers should be able to have defective "consumer goods", such as household appliances or home electronics, repaired more easily (European Commission 2023). These goals continue at the state level and are promoted in the German federal states. Technische Universität Berlin is also striving to integrate sustainability goals, ethics, and diversity into its curriculum. Since studies show that increasing awareness of sustainability leads to an increased integration into higher education (Sammalisto and Lindhqvist 2008), interdisciplinary projects may serve as a multiplier.

Similar to production-oriented and recycling-oriented designs, a shift towards repair- and maintenance-oriented designs for appliances is necessary in the medium term. Students must be taught the skills necessary to adapt to this change in the future work environment. Some of these design approaches are already part of the theoretical training, but they need to be deepened in practice. Just as the skills required for creating a design suitable for production are best acquired by gaining hands-on experience in manufacturing the components one has designed, developing a design that is suitable for repair also requires practical experimentation, including learning from negative examples.

In a preliminary teaching survey about students' needs and course topic preferences, sustainability was ranked second highest, surpassed only by the inclusion of current research topics. The big majority indicated the development of hard skills being their main learning goal, with a preference of learning technical content through hands-on formats (compare results 3.2). Since the devices to be repaired are intended for scientific use and the project aims at an intensive exchange between students and device users to gain a deep understanding of the functional principles, the presented project can fulfil many of these wishes and also combine sustainability with insights into current research topics in an interdisciplinary manner. The survey results were confirmed during the first iteration of the repair project, where it was integrated as the practice part of an already existing engineering course. 75% of students chose the repair project from a selection of six various hands-on projects.

In addition to the development of skills for the creation of repair-oriented designs and equipment, this teaching method offers the opportunity to further deepen theoretical and practical knowledge, to bring existing knowledge into the application and to support interdisciplinary exchange. In order to achieve these learning objectives efficiently, didactic methods and safety principles are required. Many common factors such as lack of goal clarity, low motivation, disorganized thinking, or mood swings can affect academic performance. Goal setting in particular plays an important role in social-cognitive learning models of academic achievement. According to psychological models, successful performance is associated with positive feedback loops between self-efficacy and goal commitment. When a student achieves a goal successfully, self-efficacy increases, which in turn increases commitment to the goal and mobilizes self-regulation of cognitive and motivational resources to facilitate further achievement (Morisano et al. 2010). For this reason, individual learning goals are developed in collaboration with mentors at the beginning of the project. These are continuously queried and reflected upon in the form of control loops.

1.2 Repairing: A way to strengthen sustainability learning goals?

Repair practices represent technical skills that allow designers to gain competencies in circular design (Terzioğlu and Wever 2021). Initially, students gain hands-on experience in troubleshooting and problem-solving, which effectively strengthens their critical thinking abilities. Repairing equipment also requires an understanding of the operating principles of the equipment, which encourages students to apply acquired theoretical knowledge to practical challenges. In addition, repairing scientific equipment promotes a deeper understanding of the importance of maintenance and sustainability in mechanical engineering. Students learn how to extend the life of equipment and reduce the environmental impact of industry by repairing and reusing equipment rather than replacing it. This is in line with the growing demand for sustainability in engineering and allows students to contribute to this important issue while developing their skills. Finally, repairing scientific equipment gives students a sense of accomplishment and pride in their work. Successfully repairing a piece of equipment provides a tangible result of their efforts and boosts their confidence and motivation to continue learning and growing in their field.

2 METHODOLOGY

2.1 Project organization procedure and didactic approach

Course assignment as repairing scientific equipment mandates a didactic approach that methodically guides students through the semester. The concept is mainly divided into two phases (compare Fig. 1): In the first phase, students are guided by mentors to independently acquire essential knowledge about the device and its operating principles. This phase also involves the development of a semester-long plan tailored to each student's individual learning objectives. During the second phase, students apply their existing and newly acquired domain knowledge, reflect on their current understanding, and expand it as needed. They also define and monitor their learning objectives, ensuring a more targeted learning experience. Mentors are available for the relevant phases, and experts are identified and involved as necessary. These can include students from other specifically required disciplines. Depending on necessity and availability, the involvement takes place on site, either online or hybrid. The mentors also assist in recruiting the experts or company members of the equipment manufacturers who contribute expertise. To deepen knowledge and integrate the interdisciplinary approach, students have the opportunity to also benefit from expert knowledge offered in various workshops. For example, problems arising from electrical engineering can be discussed and solved independently, with the help of experts, in the so-called "Soldering Lab" at Technische Universität Berlin.

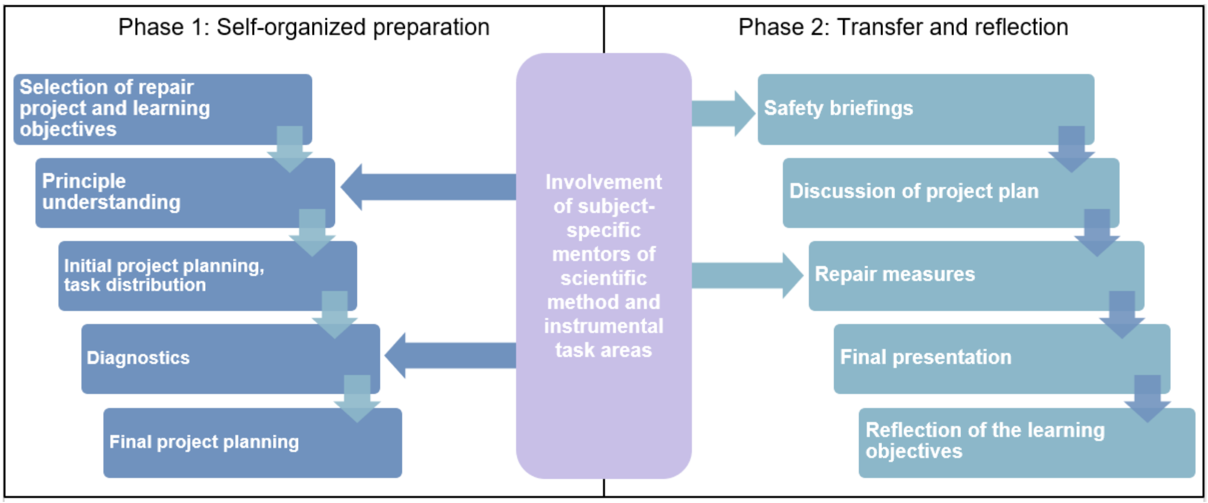

Fig. 1 Draft of didactic approach

To provide equipment, a call was launched via an existing interdisciplinary network within the university. As a result, several well-suited devices with complex operating principles were identified and collected for the repair project. Depending on the equipment, the involved departments agreed to make reusable subcomponents of the devices available to a student pool for equipment development if repair is not possible, in the interests of sustainability. Repaired devices are reintegrated into the scientific activities.

<u>Learning objectives</u>

In addition to promoting a sustainable mindset and providing a course to teach advanced engineering skills, we also support students in gaining and strengthening competencies such as teamwork, conflict resolution and leadership skills. As individual learning goals tend to have a positive impact on learning outcome, we ask students to elaborate their learning objectives in terms of soft and hard skills that they aim to achieve during the project. The elaboration of those goals is supported by the addition of a psychological online test, addressing “Past and Future Self Authoring” (Morisano et al. 2010) and discussions with the mentors at the beginning of the course. The test consists of two stages. Stage 1 involves writing a positive personal vision and a negative counter-vision in order to undergo the past authoring phase. Stage 2 involves analyzing and organizing the positive vision developed in the first stage as well as formulating a detailed plan for implementation and self-monitoring. Participants are required to title and rank-order their individual learning goals and to justify each goal from a personal, familial, and social perspective, to consider potential obstacles and strategies to overcome them, and to formulate a personal progress monitoring process. The goals are monitored and reflected on with the mentor.

<u>Preparation phase (Phase 1)</u>

Students select a repair project from the available science equipment that matches their area of interest, their area of knowledge, and their personal learning goals. A student group that is as interdisciplinary as possible allows for division into diverse learning objectives that are linked to one another. Students will try to understand the structure and (measurement/function) principle of the device on their own and discuss the results in their team. A mentor will help with the team discussion. The aim is to understand the device well and find out what additional knowledge is required. After that initial research phase, the teams develop a working plan for the semester, which includes the definition of team and individual learning objectives. Each team member is assigned a different area in which he or she is to become an "expert". This also results in different specific tasks for each team member, which are to be documented. In order to increase motivation in achieving individual goals, a continuous exchange with the mentor is encouraged to reflect on whether their choice of methods during the project phase offers promise of success (Morisano et al. 2010). Next, the most time-consuming step of phase one starts and requires the students' independent organizational skills. Together with the mentor, the student teams examine the device, identify defects and malfunctions and, consequently, learn more about the device. This may also result in new learning content, which must be assigned as a task. The step requires a problem hypothesis, a plan for testing, and, depending on the outcome, an iteration, a new hypothesis and an adapted plan for testing. Now that the problem is known, the teams finalize project planning, taking into account the repair measures, timing, methodology and necessary equipment. In the process, tasks are distributed according to the areas of expertise defined earlier. To ensure an even workload, adjustments may need to be made to the arrangements documented in their working plan.

Transfer and Reflection (Phase 2)

After determining what needs to be done, the practical implementation takes place. Since active manipulations of the equipment now begin, mentors provide mandatory equipment- and task-specific safety briefings. Especially with regard to electrical interventions, entitled expert mentors are important. We involve in-house electrician trainees for these activities. Before starting the practical work, students present their project (instrument, problems, and repair plan) to the other teams. In doing so, they learn from each other, identify possible commonalities and discuss their approaches to solve the problems. Next, the most time-consuming step of the second phase takes place. Using the test methods developed before, students implement the planned repair measures and test whether the repair was successful or not. During this process, mentors remain available as needed. Towards the end of the project, students present the results and reflect on their success or failure in a (hopefully) lively discussion. Especially in the case of failure, it should be discussed whether further work by a new group of students in the following semester may have a chance of success if building on the current results. Finally, the students summarize their results in a report and meet with their mentor to conclusively reflect on the implementation of their learning objectives and the experience gained in a mutual feedback discussion.

2.2 Numeric evaluation of teaching/learning preferences

In Winter 2022/23 we used our Moodle based learning platform to conduct a survey with the goal to learn about students' teaching and learning preferences. It was divided into several sub-areas with different relevance to different projects offered. In addition to demographics, data was collected on the use of courses and teaching media, the desire and opportunity to participate in the design of teaching topics, learning types and learning behaviors, learning goals, and about the support offered for the achievement of learning goals. Furthermore, students were asked about the relevance of topics such as sustainability and society in education, as well as motivational modalities. The aim was to compare students' desired educational experience with what they experience in university. For this purpose, point systems (1-5 points for not relevant to very important) as well as binary answer options and free-text areas were used.

2.3 Numeric evaluation of learning success

To assess participants' learning progress, we have designed a series of surveys that students complete anonymously at regular intervals. Throughout the semester, the current status of their personal learning goals (hard and soft skills) is reflected weekly via a scalar query (0 for no experience - 100 for expert).

2.4 Use case examples of systematic lab equipment refurbishment

The project aims to provide scientific devices from as diverse a range of disciplines as possible: precision mechanics, optics, fluidics and electronics. In the following, the explained procedure is illustrated by the case study of an optical device. The system chosen by the student is a special surface interferometer. The applied teaching content correlates with a master course for micro-optical systems.
First, an analogy model of the optical components was built on a breadboard in order to understand the principle and the influences. The learning objective of this methodical preparation was to build up a basic understanding of interferometry. This preparation also included an independent literature research to understand the operation of a special component used in this interferometer to reduce the so-called spatial coherence. The learning objective was to understand spatial and temporal coherence and how they affect the system. At this point, a mentor from the field of optical simulation and optical metrology was involved to realize a virtual model of the system and a mathematical analytical description that would simplify the failure analysis. It became apparent that the replacement of defective optical components and the sensor technology was necessary. The sensor replacement in particular required the development of further specific knowledge, since a low-cost open source solution was to be used. This required programming a custom software for the sensor readout, as well as introducing the open source software for data analysis. The learning objectives were an understanding of the necessary quantum sensor technology, LabView programming (laboratory software standard) and the regulations of open source software. After integrating the new components and sensor technology, a successful validation was achieved through measurement on known reference components. The whole project was documented in a final report.

3 RESULTS

3.1 Lessons learned from the case study

We interviewed the student who repaired the optical instrument featured in the case study. They shared very positive experiences during the process and expressed a strong sense of pride in the successful restoration of an otherwise lost instrument, thereby contributing to sustainability at the university. They also mentioned that they learned even more than they expected initially and explained that the didactic schedule required them to first gain a thorough understanding of the physical principles of the instrument; by using an analogy model, many of the theoretical concepts that they had only partially learned before now really made sense to them. Furthermore, they even developed ideas to improve its accuracy, showing the project’s potential to boost creativity through a hands-on high-level understanding of high precision instruments. They also underlined that having access to a supportive mentor helped them to not lose track during the project and to ultimately reach their learning goals. Not having repaired a device of any kind before, the project lowered their inhibition threshold, and they now regularly opens malfunctioning instruments and tries to repair them. This demonstrates that the project has the potential to support students in developing a sustainable mindset.

3.2 Results of preliminary survey about teaching/learning preferences

In the teaching survey about students’ teaching and learning preferences (n=21), students indicated the following: In ranking the importance of course topics, sustainability was ranked second highest (3.7/5), surpassed only by the inclusion of current research topics (4.4/5). 83% of students indicated learning objectives, with hard skills being the most important to the vast majority (76%). This was also confirmed when asked about reasons for choosing courses, with a value of 4.1/5, technical content was the highest rated reason. Having a value of 4.2/5, learning through practical activities was the most highly rated form of teaching. Also with respect to hands-on formats, hands-on activities with a sustainability focus were ranked second highest with a value of 3.7/5.

3.3 Transformation to a repair project

Based on the learnings derived from the case study, we developed the repair project as a practical course concept and measured the learning success towards their learning goals (compare section 2.1). The learning goals are freely selectable and are taken into account when choosing the appropriate device for repair. The only requirement is that each student defines at least one hard and one soft skill. The specific learning objectives are known only to the mentors. In the surveys, a distinction is only made between soft and hard skills to ensure anonymity. The top three hard skills selected by students themselves included learning new programming languages, working with electronic components and understanding new manufacturing methods. The development of understanding within their learning objectives was reflected weekly, as described in section 2.3. At the submission of this conference paper, nine weekly surveys had been conducted. The data from students who regularly completed the survey (n=3) is summarized in Fig. 2.

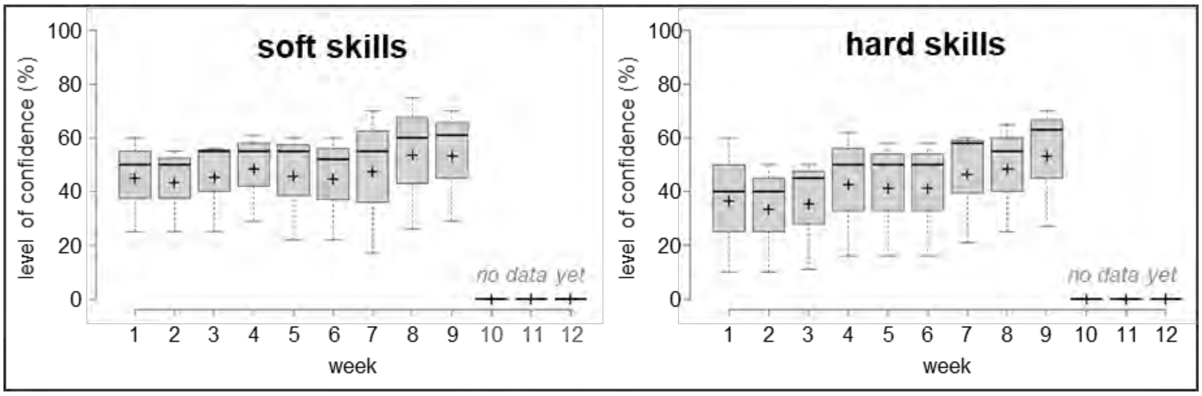

Fig. 2 Boxplots of the weekly evaluations about the development towards their hard and soft skill learning goals (scale: 0=know nothing at all, 100=feel like an expert). The mean of all answers for each students’ individual learning objective is displayed with a “+”. Please note that the last three evaluations are yet to be carried out at the time of this submission.

The data suggest that students' perceived confidence levels improved over the weeks, a trend that is corroborated by the mentors. Intriguingly, the mean decreases after the the fourth week, which was the week preceding the students' presentation

of their projects in front of their peers and scientific staff. This drop could be attributed to the students being faced with new details and deep questions. Another notable change occured in the seventh week when the students commenced their practical reparations.
Student feedback named the project format as instructive, and motivating for self-learning, and encouraged its continuation. The lessons learned from this first iteration will be used to further improve the didactic concept.

4 SUMMARY AND FUTURE DIRECTIONS

The presented project is designed to be emulated, as it provides a great learning opportunity for students while increasing the sustainability of a university as a whole. We are planning to integrate it into the curriculum and are already in contact with other self-organized repair workshops to establish a university-wide repair campus. By joining forces and competencies, we expect to create a momentum, strong enough to transform our university into a role model for repair friendly environments. Observed by the public, we expect to inspire other organizations, companies and even citizens to adopt more sustainable practices. Together with the engineers we train, we aspire to become ambassadors for circular production and repairable products in order to promote sustainability and contribute to a more sustainable world.

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DESIGNING A CURRICULUM FOR A SUSTAINABLE ENTREPRENEURSHIP MAJOR: A CASE STUDY

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Conference Key Areas: *Curriculum Development, Embedding Sustainability and Ethics in the Curriculum*
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ABSTRACT

This practice paper explores the process of developing a curriculum for a sustainable entrepreneurship major program in a higher education institution. The paper aims to address the need for embedding sustainability and entrepreneurship into higher education, considering global challenges such as climate change, social inequality, and unsustainable consumption and production. The paper fills a gap in the existing body of knowledge by providing a case example of a curriculum development process that can be adapted to integrate sustainable entrepreneurship into curricula at other universities.

The paper outlines a three-part curriculum development process which involves identifying stakeholders and clarifying the program's purpose, determining program-level learning outcomes, and developing courses that align with the program's purpose and intended learning outcomes. The paper's findings emphasize the importance of involving stakeholders (such as faculty members, potential students, alumni, industry professionals and decision-making bodies within the university) in curriculum design. The paper concludes with a discussion on the iterative nature of identifying program-level learning outcomes, the challenges of balancing dual themes from a rapidly changing field of study in the curriculum, and academic resource limitations. A well-designed sustainable entrepreneurship major can benefit students, faculty, business and industry, and society at large by providing the knowledge, skills, and opportunities necessary for socially and environmentally responsible entrepreneurship.

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1 INTRODUCTION

This practise paper explores the author's experiences in developing a curriculum for a sustainable entrepreneurship major program. Sustainable entrepreneurship refers to the “discovery, creation, and exploitation of entrepreneurial opportunities that contribute to sustainability” (Brazdauskas and Žirnelė 2018). The need for integrating sustainability and entrepreneurship into higher education is growing due to global challenges like climate change, social inequality and unsustainable consumption and production (United Nations, 2023). This paper fills a gap in the existing body of knowledge by describing the curriculum development process of a sustainable entrepreneurship major that can be adapted to embed sustainable entrepreneurship into curricula at other universities.

The paper is structured as follows: Section 1.1 discusses the context and scope of this paper, while Section 1.2 delves into the educational theory that informs the curriculum development process described herein. Section 2 discusses the process in three parts: 1) identifying stakeholders and building understanding about the program's purpose, 2) identifying relevant program-level learning outcomes, and 3) developing courses that align with the program’s purpose and intended learning outcomes (ILOs). Section 3 presents findings, and finally, Section 4 contains conclusions, limitations and implications, and an exploration of the broader relevance of the case example discussed in this paper.

1.1 CONTEXT

This paper outlines the process of developing a curriculum for a new sustainable entrepreneurship major at Aalto University in Finland, a public research university with schools in Engineering; Electrical Engineering; Chemical Engineering; Science; Business and Arts, Design and Architecture. The focus is on the design and preparation process of the curriculum, excluding the formal decision-making process of the university, course-level pedagogy and program evaluation. It is important to note that the development of the program is still a work in progress at the time of writing, with the first cohort set to begin their studies in 2024.

The paper contributes to the ongoing academic discussion on how to prepare students to become sustainable entrepreneurs. Research has suggested that sustainable development is increasingly seen as a key mission of HEIs (Alm et al, 2021). Bonnet et al (2006) state that “sustainability, development of personal skills, social aspects of technology and entrepreneurship are of increasing concern for engineers and therefore also for engineering education”. Wiek et al. (2011) have conducted a broad literature review on key competences in sustainability education, concluding that they include systems thinking, anticipatory, normative and strategic competencies combined with interpersonal competence, critical thinking and communication. However, a challenge of embedded sustainability practice in entrepreneurship education is that it is typically limited and regarded as an “add-on” to traditional entrepreneurial teaching (Wyness et al, 2015).

1.2 THEORY

The curriculum development process in this paper is guided by Biggs' principle of constructive alignment. Constructive alignment, originally focused on designing teaching and learning activities such as courses, can also be applied to larger educational entities like curricula (Biggs 2003). The theory emphazies that that learners construct their own knowledge through relevant activities.

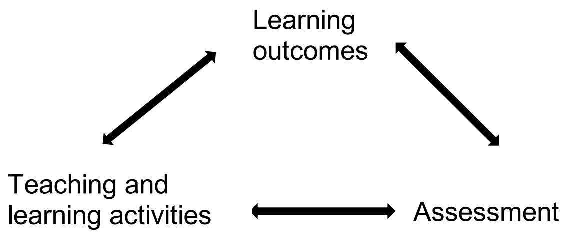

Fig. 1. Constructive alignment (Biggs 1996)

The process of constructive alignment involves aligning ILOs, teaching and learning activities, and assessment tasks. Designing engaging teaching activities and appropriate assessment ensures effective learning and achievement of ILOs. Alignment facilitates students in attaining their desired learning outcomes.

2 METHOD

The curriculum development method used in this paper follows Biggs' principle of constructive alignment. The process consists of three parts: 1) identifying stakeholders and clarifying the program's purpose, 2) determining program-level learning outcomes, and 3) building alignment between purpose and teaching by identifying and developing courses to meet the program’s purpose and ILOs. This section provides an overview of the key steps taken to support each stage in the case example.

2.1 Identifying stakeholders and building understanding about the purpose of the program

The curriculum design process involved engaging with 5 different stakeholder groups: 1) faculty members, 2) potential students, 3) alumni from related fields, 4) industry professionals and 5) decision-making bodies within the university. The first group, faculty members from two units from the schools of Science and Business, initiated discussions on co-developing a new major program during a curriculum development course in 2022. Joint meetings with the cooperating units followed, and established a plan of action, roles and responsibilities, program-level ILOs, and a preliminary program structure.

The second group, potential students, provided input through a survey on entrepreneurial mindset and informal discussions during entrepreneurship courses. The survey was sent out to 13,066 students enrolled at the university in November 2022, and received 824 responses (Aalto Ventures Program, 2022). The survey included questions on entrepreneurial mindset, student interest in starting a company, their views on their own entrepreneurial skills and capabilities, and whether they saw solving sustainability-related problems as a motivator to becoming an entrepreneur. The third group, alumni, was represented through data from a third-party graduate survey (Tekniikan Akateemiset, 2022). The survey included data on student’s self-reported expertise on entrepreneurial capacities, as well as employment data, which was used to help chart employment prospects after graduation for the proposed program. The survey was sent out to 2,921 graduates, of whom 1,785 answered. Only the responses from Aalto University graduates, comprising 53% of the total respondents, were used in the curriculum design process.

The fourth group, industry professionals, contributed through discussions conducted in the spring of 2023. Themes included what knowledge and skills the 7 locally influential entrepreneurs had found useful in their own careers as entrepreneurs, and what they would like to see being taught in a sustainable entrepreneurship program in the future. Their input was used to inform the ILOs outlined in the next section. The fifth group, decision-making bodies within the university, were consulted to ensure compliance with regulations and accreditation requirements.

2.2 Identifying program-level ILOs

The process of identifying ILOs involved integrating data from the surveys and stakeholder discussions described in the previous section. The process began with faculty discussions on what courses teaching staff were currently working on, what they would be interested in (and committed to) teaching that is not currently being offered, and how they see the future of the program under development. Subsequently, a series of workshops with teaching staff was conducted to establish development goals, identify potential collaborations, and begin drafting program-level ILOs. At the time of writing, the program-level learning outcomes include the following:

- Understand the principles of entrepreneurship and the systemic nature of social, environmental, and economic sustainability challenges
- Understand how entrepreneurship can impact sustainability challenges and vice versa
- Apply scientific knowledge to critically evaluate the sustainability potential of entrepreneurial opportunities
- Cultivate an entrepreneurial mindset to address sustainability challenges in a variety of managerial settings and roles
- Develop the essential soft and hard business skills to experiment with and create sustainable new ventures

2.3 Building alignment between purpose and teaching

After identifying program-level ILOs, the next step in the curriculum development process was to ensure their alignment with teaching and learning activities. First, we identified existing courses related to entrepreneurship and sustainability already being taught at the two units collaborating on the program. Second, we conducted a search for other suitable multidisciplinary courses on offer using the university's course database. Third, we began discussions with the teachers of these courses regarding their willingness to allow the students of the proposed new program to enroll in their classes. The result was a list of available courses suitable for the program.

The list of suitable existing courses was then mapped against the program-level ILOs (Appendix 1). Thematic color-coding was used to help make the balance between entrepreneurship-related courses and sustainability-related courses easier to visualize. Identified gaps included a theory-based foundations of entrepreneurship course, a startup leadership course, an entrepreneurial financing course, and a capstone course.

Next, the course lists were divided into core content and electives. Core content was divided into three core elements or "pillars" – sustainability, entrepreneurship and "hard skills" such as finance and law, to ensure adequate breadth and depth of knowledge (Figure 1). Electives were divided into two tracks based on graduate career prospects derived from our stakeholder discussions: the sustainable startup track (for those interested in founding or working in a startup), and the sustainable corporate entrepreneurship track (for those wishing to work in the entrepreneurship ecosystem in a non-founder role).

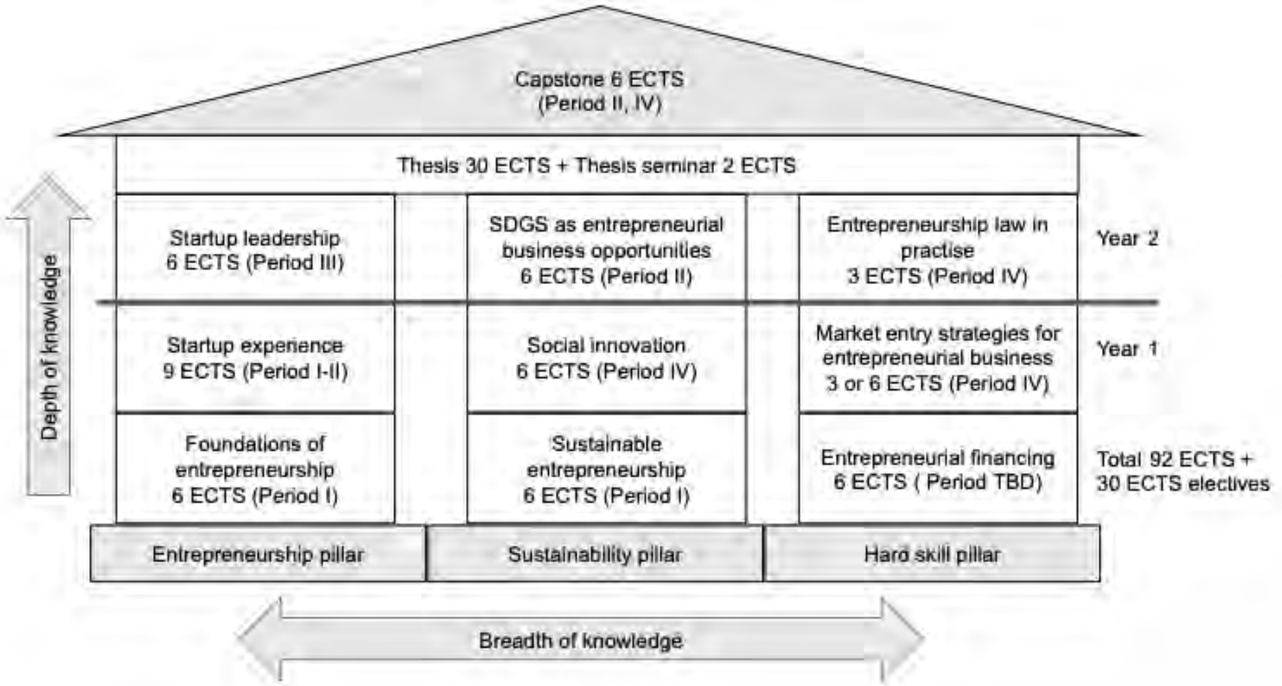

Fig. 1. Breadth and depth of core content

Benchmarking existing capstone courses in leading entrepreneurship programs was used to help design the proposed new capstone course. Common themes in the 10 benchmarked courses included offering students the opportunity to apply their entrepreneurship knowledge, tackle real-world challenges, network with experienced professionals, and receive feedback and mentorship while launching their ventures. Faculty from the two collaborating units were then invited to a series of ideation workshops to discuss the potential new courses and to make plans for their intitiation.

3 FINDINGS

This section describes the key findings from the background research conducted during the development process of the program. First, the student survey on entrepreneurial mindset showed that students' perceptions of entrepreneurship were mostly positive or neutral (46% positive, 46% neutral, 8% negative). Similarly, student interest in starting a company of their own was positive, with 15% saying they see themselves starting one in over 10 years, 38% saying that they see themselves starting one in 4-10 years, 13% in the next 3 years, 10% saying they have already had one, and 23% have no interest in starting a company. Interestingly, 32% of respondents saw solving sustainability-related problems as a motivator to becoming an entrepreneur.

Table 1. Student interest in starting a company of their own (AVP, 2022)

Already have	In 0- 3 years	In 4-10 years	In 10+ years	Never
10%	13%	38%	15%	23%

An interesting finding from the alumni survey was that 5 years after graduation, graduates ranked the perceived importance of expertise and skills in “entrepreneurial capacities” for their own career the lowest of 30 types of skill listed, ranking at 4, or “somewhat important” on a scale of 1-6. This can perhaps be accounted for by the fact that only 2% of the respondents were working as full-time entrepreneurs upon graduation, with 6% reporting part-time entrepreneurship (TEK, 2022). While the questions asked in the graduate survey were not the same as those in the student survey, the contrasting results (total 23% interest in starting their own company within 3 years for students, and 8% full or part-time entrepreneurship rate 5 years after graduation for alumni) show a shift in attitudes towards a more positive approach to entrepreneurship, and a need for more support to help dreams become reality.

These findings were used to inform the curriculum development process, which involved three stages: 1) identifying stakeholders and clarifying the program's purpose, 2) defining program-level learning outcomes, and 3) aligning teaching with the purpose and outcomes through course development.

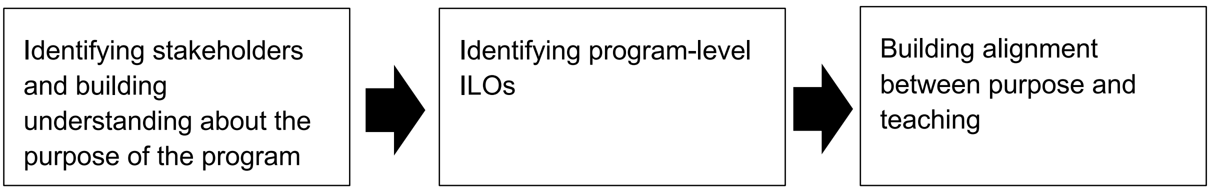

Fig. 2. Curriculum development process

First, engaging stakeholders and building understanding of the program's purpose were crucial in developing a relevant and high-quality curriculum. Collaboration with faculty fostered ownership and buy-in, while surveys and discussions with students and alumni revealed their expectations and career prospects, as well as testing the applicability of the ILOS to graduate experiences. Discussions with industry professionals helped identify areas of improvement, and feedback from university decision-makers ensured regulatory compliance.

Second, the identification of relevant program-level learning outcomes was an iterative process. The ILOs evolved several times as new information was uncovered via interaction with stakeholders. Third, building alignment between purpose and teaching was especially challenging as the program combines two elements: sustainability and entrepreneurship. Balancing the two themes and avoiding a disjointed approach required careful consideration. We’ve attempted to take this into account in our planning by consulting experts from both fields, and and by allowing students to design a part of the curriculum themselves by selecting electives.

4 CONCLUSIONS

This practise paper presents a comprehensive overview of the steps and considerations in designing a curriculum for a sustainable entrepreneurship major. The curriculum development process involved three stages: 1) identifying stakeholders and clarifying the program's purpose, 2) defining program-level learning outcomes, and 3) aligning teaching with the program's purpose and intended learning outcomes through course development. While focused on a specific context, this methodology can be applied to other educational settings with some modifications.

In the case example, identified stakeholders included faculty members, potential students, alumni from related fields, industry professionals and decision-making bodies within the university. Inputs from potential students, alumni and industry professional were used to formulate the ILOs, while discussions with faculty and decision-making bodies were used to help structure the core content and build alignment between ILOs and teaching activities.

Designing a current and relevant curriculum in the dynamic fields of sustainability and entrepreneurship is challenging due to the risk of rapid obsolescence caused by emerging practices, technologies, and challenges, compounded by the time lag between development and implementation. Striking a balance between depth and breadth of knowledge within the two year timeframe of the study program may also required trade-offs. In the case example, incorporating hands-on elements and practical experiences, such as problem-based learning, are used to help students grasp the practical applications of sustainable entrepreneurship. Students are encouraged to develop and test a business concept and minimum viable product, addressing a genuine customer need while promoting sustainability.

Developing and implementating a sustainable entrepreneurship curriculum requires resources, such as faculty expertise, research funding, and access to sustainable business networks. HEIs wishing to develop a similar curriculum may encounter limitations in resource allocation, affecting the breadth and depth of the curriculum. Collaboration with industry partners is vital for relevance, but it can be challenging and resource-intensive to coordinate. In this case example, resource limitations were manageable due to the interdisciplinary nature of the program, with staff from two units collaborating on the design. The dual unit structure also increased the need for co-ordination, making the role of program manager especially important.

4.1 Limitations and implications

The main limitation of this study is its narrow scope, focusing on the curriculum development process of a sustainable entrepreneurship major in one context. Consequently, the findings may not be directly generalizable to other educational settings. Second, it does not provide insights into the actual implementation of the program, as it is based solely on the curriculum development process. This study emphasizes the need for further research to expand the knowledge base on sustainable entrepreneurship curriculum development. Investigating different settings, alternative approaches, and conducting comparative analyses could identify best practices, while longitudinal studies could assess program effectiveness.

A well-designed sustainable entrepreneurship curriculum has practical implications for multiple stakeholders. For students, it can offer knowledge and skills needed to create and manage businesses that are socially and environmentally responsible. For faculty, it can foster interdisciplinary collaboration and create opportunities for research, teaching and engagement with the community. For practitioners in business and industry, it can provide graduates who are equipped with the ability to address sustainability-related challenges and create socially and environmentally responsible businesses. Ultimately, a sustainable entrepreneurship curriculum cultivates graduates who are able to become community leaders, creating businesses that prioritize the well-being of people and the planet.

5 ACKNOWLEDGMENTS

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APPENDIX 1: CURRICULUM MAPPING OF CORE COURSES WITH PROGRAM-LEVEL ILOS

	Understand the principles of entrepreneurship and the systemic nature of social, environmental, and economic sustainability challenges	Understand how entrepreneurship can impact sustainability challenges and vice versa	Apply-scientific knowledge to critically evaluate the sustainability potential of entrepreneurial opportunities	Cultivate an entrepreneurial mindset to address sustainability challenges in a variety of managerial settings and roles	Develop the essential soft and hard business skills to experiment with and create sustainable new ventures
Foundations of entrepreneurship	x	x		x	x
Startup experience	x			x	x
Startup leadership				x	x
Market entry strategies for entrepreneurial business			x	x	x
Social innovation		x	x	x	
Entrepreneurship law in practice			x		x
Entrepreneurial financing			x		x
SDGs as business opportunities	x	x	x	x	
Sustainable entrepreneurship, markets, and systems change	x	x	x		
Capstone	x	x	x	x	x
Thesis + seminars	x	x	x		

Exploring Strategies to Promote Engagement and Active Learning through Digital Course Design in Engineering Mathematics

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***Keywords**: Engineering education, mathematics, digital course, prior knowledge*

ABSTRACT

This research explores the strategies and techniques used to foster and promote the engagement and active learning of engineering students within a digital course. This digital course has been developed to address the varying levels of understanding of fundamental mathematics among first-year engineering students, who often have disparate levels of prior knowledge at their high school completion. We observe an increasing need to bridge the widening gap between high school and university mathematics in order to prevent engineering students from being hindered in their academic successes due to a lack of prior mathematical understanding. With a team of engineers and mathematicians, both researchers and educators, we are developing a mathematics *Bridging Course* including the use of digital tools, such as videos, online interactions and technology-based assessments. These sources were created, investigated and/or modified to develop an engaging learning environment in which students are made aware of and guided through misconceptions and mistakes in their understanding of fundamental mathematics. In the development of this *Bridging Course*, we consider the importance of interactive learning and timely feedback for student learning. We investigate the impact of digital course design on students' performance and learning outcomes using a qualitative approach. Students feedback within the first stage of the implementation of the course offered a positive assessment of the course, accentuating its inherent advantages and attributes. The students' feedback proved to be an invaluable source of insights, specifically concerning the enhancement of question distractors, thus prompting revisions and augmentations in the assessment items employed.

1 INTRODUCTION

1.1 Literature Review

The phenomena of the mathematics knowledge gap between high school and university manifest itself regardless of time and country (e.g. [1,2,3,4]). Bridging this gap from high school to university level is crucial for first-year engineering students as it lays a strong foundation for the complex mathematical concepts as well as problem-solving skills required in their studies and professional career. However, whether first-year engineering students are coming from high school, a post-secondary program or another route of study, the linking of high school mathematics to university mathematics is a common challenge. First-year students struggle with teachers' unawareness of their background level [5], experience high failure rates in mathematics courses [6, 7], and as a result, even drop out of the program [8].

Developing understanding and confidence in first-year students is key for their development as autonomous learners [9]. Enabling students to bridge the gap in their mathematics knowledge between high school and university will boost their understanding and confidence. Hence, it is crucial to activate first-year students in their learning process to develop the necessary knowledge and skills to succeed in consecutive, more advanced mathematics courses throughout their academic curriculum. Active learning, with its focus on learner-centred approaches, engagement, and immediate feedback, is a highly effective method for supporting students in developing their mathematical knowledge and preparing them for success in their chosen professions [10].

1.2 This Study

In the Civil Engineering (CE) Bachelor's program at the University of Twente (UT), we are also facing the mathematics knowledge gap among our first-year students. First-year CE students increasingly struggle to pass their first courses in (fundamental) mathematics at the University, affecting their academic development and progress throughout the study program. In our case specifically, a change from a Dutch-taught study program to a fully English-taught program (in 2018) stimulated the admission of international students into our Bachelor's program, further increasing the diversity in students' prior mathematics knowledge.

To shed light on this knowledge gap, we asked CE students to take part in an online prior knowledge test that was developed to assess their active understanding of mathematical topics such as solving equations, algebra, trigonometry, exponents and logarithms, and differentiation and integration. In the academic year of 2022-2023, 87 first-year CE students participated in this mathematics prior-knowledge test. Figure 1 represents the results of this test and indicates that the majority of the students had less than 75% competency in most of the mathematics topics that are assumed to be prior-knowledge.

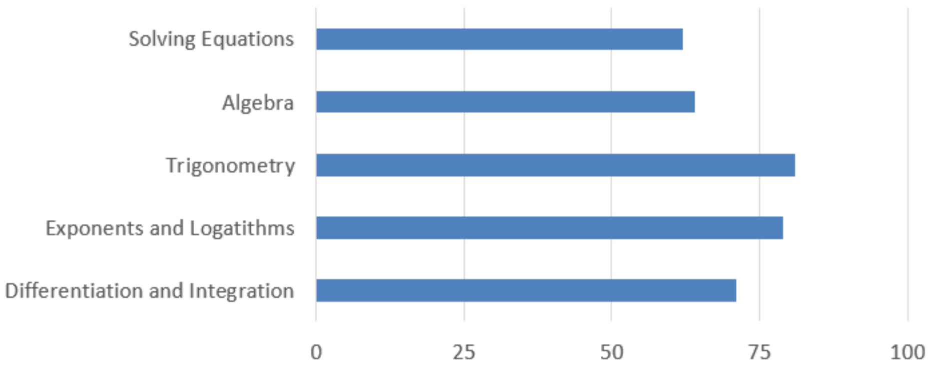

Fig. 1. Results of the prior knowledge test under 87 first-year Civil Engineering students. Results are indicated by correct answer percentages per topic.

To support our CE students with their prior mathematics knowledge, we are now developing an online platform providing a *Bridging Course* to concurrently test and support students in their pre-university mathematics. This *Bridging Course* provides the students with feedback and resources to evaluate and eventually improve their initial mathematics skills. Simultaneously, this online platform will equip teachers with the currently lacking quantitative information on students' pre-knowledge in mathematics. We will assess the efficacy of this *Bridging Course* on the mathematical attainment of students. In this study we aim to investigate the impact of the digital course design of the *Bridging Course* on students' performance and learning outcomes using a qualitative approach.

2 METHODOLOGY

2.1 Developing the Bridging Course

We are developing the *Bridging Course* in CANVAS, which is the standard online learning platform at UT. The *Bridging Course* will cover foundation mathematics for engineering students according to four main topics: arithmetic, algebra, functions, and geometry. Each primary topic is subsequently partitioned into subtopics, each of which introduces its individual learning objectives and skills to be tested. Specifically, the *Bridging Course* covers an extensive array of subjects to ensure that engineering students are equipped with the prerequisite knowledge required to undertake higher-level university courses at UT, such as Calculus I and consecutive courses. The selection of the topics and the subsidiary topics of the *Bridging Course* is based on (i) an analysis of the areas within the Calculus I course where students are typically deficient in foundational knowledge, as well as (ii) an assessment of the topics and skills that high school students frequently encounter difficulties with, and are susceptible to misconceptions and mistakes.

In order to provide additional insight into the approach and methodology behind the *Bridging Course*, the main topic 'arithmetic' and the subtopic 'fractions' will be employed as an illustration of the composition and progression of the course (see Table 1).

Table 1. An illustration of the main topic, its subtopic, and the related learning objectives

Main topic	Subtopic	Skills	Learning objectives
Arithmetic	Fractions	Addition /Subtraction	Students will be able to identify, add and subtract fractions with different denominators and mixed numbers and simplify the results to the lowest terms.
		Multiplication /Division	Students will be able to demonstrate an understanding of fraction multiplication and division, including the ability to identify and apply the appropriate operation, calculate a fraction product or quotient and explain the relationship between multiplication and division of fractions.
		Comparison	Students will be able to compare fractions with different numerators and denominators, as well as recognize which fraction is greater or lesser than another.

The *Bridging Course* digital platform will consist of two phases (see Figure 2): a testing phase and an instructive phase.

The testing phase of the *Bridging Course* consists of a wide range of start-up questions prepared by the researchers. These questions were considered to cover prevalent misconceptions and mistakes. The start-up question aims to ascertain whether the student understands a particular subtopic and possesses the relevant skills required to answer the question. The *Bridging Course* exclusively employs questions of the multiple-choice, true/false, or drag-and-drop type, with no open-ended questions included. The response to the start-up question serves as a determining factor as to whether the student needs to continue with the instructive phase. If the student correctly answers the question, they can move on to the next question, but they can also choose to proceed with the instructive phase for the particular subtopic of the question. Conversely, if the student's answer is incorrect, they are automatically directed towards the instructive phase.

During the instructive phase, students are directed to video recordings that expound upon the learning objective of the specific subtopic that is addressed by the preceeding start-up question. The selection of videos for the instructive phase is based on both publicly available open-source material online as well as instructive videos that are generated by the team. When no suitable open-source material is available, new instructive videos will be recorded by the team to ensure that all topics are comprehensively addressed in a single source, and to ascertain that all explanations are aligned with the prerequisite knowledge required to support students in meeting the expected attainment outcomes for the Calculus I course at UT. Of particular importance in the selection and development of these videos is the prioritization of conceptual understanding of topics over students' mere execution of procedures.

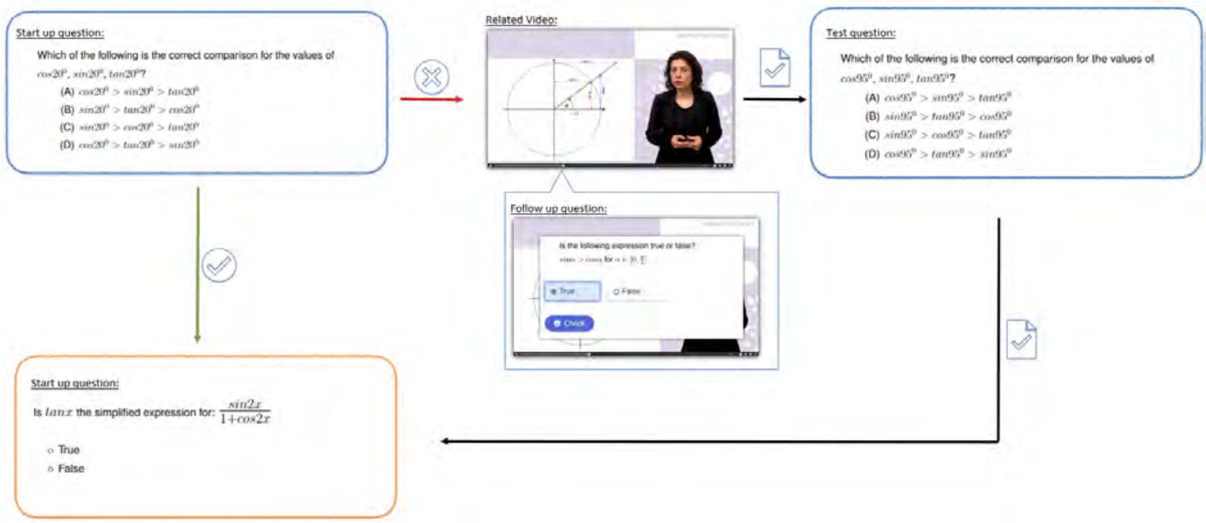

Fig. 2. Setup of the Bridging Course with the testing phase (left-hand side) and the instructive phase (right-hand side).

The instructive videos contain embedded follow-up questions, which serve to ascertain whether the students are actively engaging with the content to facilitate their learning. Upon completion of each video, a concluding question identical to the start-up question is presented, to assess the level of students' newly obtained comprehension of the subtopic. This marks the final point to understanding students' comprehension of the relevant subtopic and the next step is to present the start-up question of the following learning objective.

Upon final completion of the *Bridging Course*, students receive feedback on their comprehension of all topics and subtopics, expressed as correct-answer percentages. Additionally, students are provided with feedback on their most proficiently grasped subtopics and those which require further study. This feedback will include links to the videos fo the instructive phase. The instructive phase will remain accessible to students for repetition and review throughout the academic year.

2.2 Evaluating the *Bridging Course*

The implementation of the *Bridging Course* will be carried out in two stages. Firstly, the course was presented to a panel consisting of 6 CE students for evaluation. Secondly, the course will be implemented during the first quartile of the academic year 2023-2024 among all first-year CE students at UT. The evaluation of the second stage of the implementation, in September 2023, will be quantitative in nature, whereas the qualitative results of the first stage will be shared in this study.

For the first stage of the implementation of the *Bridging Course*, six CE students completed the *Bridging Course* at their own pace and convenience. The selection criteria for the students encompassed an assessment of their relevant skills and experience, taking into account their varying academic development as both master and bachelor level candidates were included. Upon completion, the students underwent a group interview session where discussions addressed the *Bridging Course* as a whole, as well as each learning objective and the related start-up and follow-up questions, including the provided video materials.

3 RESULTS & DISCUSSION

At the current stage of our study, we focus on the qualitative results of the first stage of the *Bridging Course* implementation. It is noted that the second stage of the implementation, which is not covered in this study, is yet to be conducted.

The feedback provided by the interviewed students regarding the course was predominantly positive, with an appreciation for its academic merits and benefits. Students noted that the *Bridging Course* offered them a comprehensive understanding of both the anticipated level of mathematics and their own proficiency within that level. During the interview also the technical issues, such as malfunctioning buttons or videos, were identified and duly addressed, assuring the students these issues would be solved prior to full implementation of the *Bridging Course*.

It is noteworthy to highlight the feedback by the interviewed students yielded valuable insights, particularly pertaining to the improvement of question distractors. In response to this feedback, revisions were made to incorporate stronger distractors, thereby enhancing the quality of the assessment items. Furthermore, the students' observations regarding the discrepancy between follow-up and start-up questions were useful and incorporated, ensuring equivalence and consistency in the final version of the *Bridging Course*.

Regarding the instructional videos, the majority of students found them to be beneficial for learning. Two videos were identified and discussed by the students. Some students found one of the videos lengthy, approximately spanning 8 minutes. Another video was advised to be considered to be replaced with an alternative video that is more closely aligned with the content of the start-up question. These concerns were examined, leading to necessary modifications to rectify the problems.

The performance of the six students in the *Bridging Course* assessment was of remarkably high level. However, we would like to note that these results will not be reported as part of this study's findings. This decision is based on the fact that the students were explicitly encouraged to freely explore and identify any shortcomings within the system. Consequently, some students deliberately chose incorrect answers as part of their conscious effort to fulfil this objective. As a result, the reported performance may not accurately reflect their actual mastery of the course material.

This preliminary study has certain limitations that should be acknowledged. As the course is delivered in an online learning environment, no open-ended questions can be used. While the questions and potential answers have been designed based on expected misconceptions from literature and teaching experience, students may come up with answers that are not accounted for in the course materials. Based on the results of the second stage of the study, several recommendations for further research will be presented. One of the main recommendations will be to implement this course in various disciplines and at different universities to assess its effectiveness within a range of engineering and university contexts.

4 ACKNOWLEDGMENT

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HOW DOES COMMITMENT IN STUDENT ASSOCIATIONS CONTRIBUTE TO THE DEVELOPMENT OF AN ENGINEER'S SKILLS? EXAMPLE OF MAGIEPOLY: RAISING AWARENESS OF GENDER EQUALITY THROUGH GAMES.

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Conference Key Areas: *Equality Diversity and Inclusion in Engineering Education, Engineering Skills and Competences.*
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ABSTRACT

Some engineering students get involved in student associations during their studies. They develop multiple skills such as: leadership and management, communication, project management, supervision and transmission of knowledge, service to others, etc. However, they are not always aware of it.

Helphi, a student association of EPF Engineering School, was responsible for organising an afterwork event to be held on International Women's Rights Day. As student members were brainstorming, the idea of a board game, both informative and entertaining came up: MagiePoly was born. MagiePoly is a game, inspired by a well-known board game, which aims to raise awareness of gender inequalities.

During their studies, engineering students have access to an eportfolio, but they do not always have the habit of using it to identify how they develop their skills, what they need to improve or how their career plans could evolve. Students also attend an introductory course on the research process. It is within the framework of this course that students co-write with their teacher an article on the acquisition of engineering skills through involvement in student associations.

This article describes how the creation of MagiePoly has contributed to the engineering students' skills and how the realisation of a project have been key to the motivation, commitment and success of these students.

1 INTRODUCTION

Student engineers at EPF Engineering School are trained to be aware and face society’s challenges, technological issues, and organisational changes to come. During their academic studies, students carry out a variety of technical projects or innovation challenges. These projects prepare students for their professional career, as they collaboratively solve engineering problems.

As commitment is a key value for EPF Engineering School, student engineers should be committed to the school's life. This commitment can be made in a variety of ways in extra-curricular activities and will enable to develop some of the following skills: leadership and management, communication, project management, supervision and transmission of knowledge, service to others, etc.

Some engineering students get involved in student associations during their studies. Helphi, a student association of EPF Engineering School, was responsible for organising an afterwork event to be held on International Women's Rights Day. As student members were brainstorming, the idea of a board game, both informative and entertaining came up: MagiePoly was born. MagiePoly is a game, inspired by a well-known board game, which aims to raise awareness of gender inequalities.

During their studies, engineering students have access to an eportfolio, but they do not always have the habit of using it to identify how they develop their skills, what they need to improve or how their career plans could evolve. As the MagiePoly’s creators were not aware of the skills they developed and as they underestimated the impact their game could have on their peers, we decided to analyse and share this experience.

1.1 Aim and questions

In this paper, we will focus on students' engagement in student associations and the developed skills in one particular project within an association: The MagiePoly. The story of this project traces the stages of joint analysis by the students and their teacher to understand the success of the project and analyse the skills that have been developed.

- Why were the students involved and why did they carry out this project?
- What skills were developed?
- What can we learn from this experience?

2 METHODOLOGY

The investigation begins with a review of the state of the art on student motivation, followed by analysis of a survey and interviews.

2.1 State of the art

Students were asked to find in the literature the key elements of student motivation.

2.2 Qualitative analysis

A teacher interviewed two students involved in the MagiePoly project: the president of the Helphi association and the creator of MagiePoly. Two interviews were conducted. These students themselves conducted interviews with participants of the MagiePoly.

Qualitative data will be extracted from these different interviews.

2.3 Quantitative analysis

A survey was offered to students and workers on campus. The aim of the survey was to assess the achievement of the initial objectives of the game and to identify future participants or facilitators of the game. 56 people took part in the survey. The survey contains 4 closed questions and 3 open questions.

3 ANALYSIS

3.1 Student engagement, motivation, volition, and persistence

Based on the literature, we consider **student engagement** as proposed by V. Trowler in (Trowler 2010):

> *Student engagement is concerned with the interaction between the time, effort and other relevant resources invested by both students and their institutions intended to optimise the student experience and enhance the learning outcomes and development of students and the performance, and reputation of the institution.*

Studies have shown how motivational and cognitive factors interact and influence student learning and achievement. Three key dimensions of student **motivation** have been proposed (Tinto 2017): ***self-efficacy*** that is a person's belief in their ability to succeed at a particular task; ***sense of belonging*** that refers to students that can see themselves as a member of a community of other students, academics and professional staff who value their membership and the ***curriculum*** through the perception of the **value** of what they are being asked to learn.

People's **volitional processes** refer to their desires, wants, or purposes together with a belief about satisfying them and converting intentions into actions (Keller, 2012).

Motivational persistence is defined as a person's predisposition to persist with the effort to achieve a selected goal, finding the personal resources to overcome the obstacles, fatigue, stress, and other distractors (Constantin, 2008).

3.2 Student analysis of their engagement

During the interviews conducted by the teacher, the students explain that the **value** of this game's project resides in its origin.

Helphi is a charity organisation that aims to educate and organise different events around the theme of ecology and human rights. Helphi decided to organise an afterwork for the entire organisation. As they were looking for an idea for the solidarity branch stand, a student member of the association, came up with the idea of a militant board game: an informative and entertaining game. As the event took place on March 8, International Women's Day, the idea was to bring attention to issues such as gender equality, reproductive rights, and violence and abuse against women.

> *Our aim was to challenge the ideas in the minds of the students. We have already been confronted with people who are opposed to discussing gender inequality and/or systematic and racial oppression.*

In France, Monopoly is a well-known boardgame. It was assumed that the greatest part of the audience would already have a knowledge of the rules and the goals of the game.

The theme was obvious to them due to the injustice or discrimination they've been through, or they witnessed since their youngest age.

> *We - as women identifying person - are the witnesses of the inequalities we face, but also inequalities that affect other people. […] It can sometimes be difficult to communicate and create a dialogue between people with different point of view. […] We were and still are never allowed to be mediocre. To hope for a place and engage in your sport without facing discrimination, always having to be the best or do not attempt it at all.*

Discrimination, bullying, or high expectation were present especially in schools and in sport~~s~~ teams.

Raising awareness of gender inequalities among their peers is what makes this project so valuable to the students.

As the students were created the game on their own, they could easily choose or adapt their tasks to their abilities. The need of **self-efficacity** was then fulfilled.

A benefit of the success of Magiepoly is the **feeling of belonging**. As this is an awareness-raising game, one of the objectives is to help peers develop and feel more at home in their school.

The value, sense of belonging and self-efficacity have allowed MagiePoly creators to reinforce their **volition** and **persistence** by carrying out the project.

4 MAGIEPOLY

This section presents the MagiePoly created by Helphi's student members.

4.1 Game's adaptation

The main differences between Monopoly and MagiePoly are:

- the spaces on the game board (property spaces with names of women activists);
- there are spaces related to domestic violence, regulation and contraception have been created, train stations are replaced by babies (Fig. 1);
- the currency (Women money);
- facilitator's guidance throughout the game;
- game ending: whilst the objective is the same as Monopoly, different endgame scenarios are possible depending on the time available.

Title cards contain information about the woman and her fights or achievements, for instance Marsha P. Jonhson, Ruth Badden Ginsburg, Malala or Rosa Parks.

As an objective of Helphi is to reduce waste, the choice was made not to create tokens but to use tokens borrowed from other boardgames.

Fig. 1. MagiePoly's game board

Fig. 2. Participants playing MagiePoly
(Image credits: Apostrophe)

Playing the game (Fig. 2):

1) Players start to randomly choose a blue or pink card, which represents a gender stereotype, while ensuring inclusivity without reference to gender.
2) Afterwards, they play the game with a facilitator who explains each box and narrates the story of each woman. Some spaces have a different impact on the game depending on the gender card picked;
3) As the game board and the women involved in the fight for women's rights are discovered, discussions and debates are welcome. The role of the facilitator is key in ensuring that the game runs smoothly.
4) The game ends: when a player runs out of money, when all boxes have been purchased, when one player owns all boxes of one color, or when players simply decide to stop the game.
5) At the end of the game, the facilitator talks to the players about their feelings and the information they have learned during the game.

5 RESULTS

To assess whether the game has achieved its objectives, we are analysing the results of the survey.

5.1 Game's reception

Participants were asked whether they found the MagiePoly informative and entertaining on the following scale: strongly disagree, disagree, agree, strongly agree. Results show MagiePoly reached its objectives: more than 90% of the participants found the game instructive (Fig. 4), and all of them have felt entertained (Fig. 3).

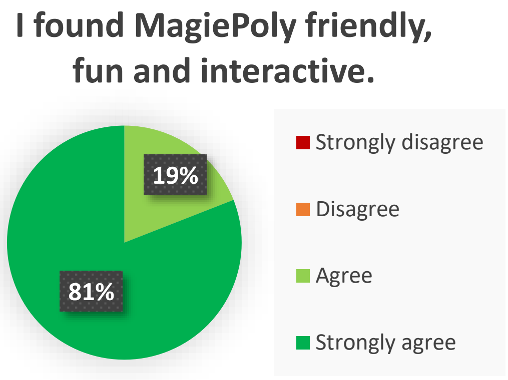

Fig. 3. Participant's perception of the entertainment value of MagiePoly

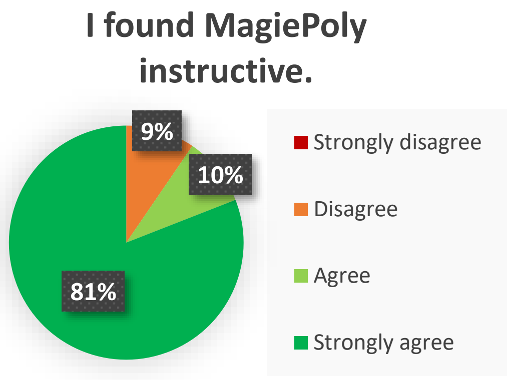

Fig. 4. Participant's perception of the instructive value of MagiePoly

The main information retained is the names of women activists, the nature of their fights, some gender inequalities, the pay gap, and the fact that the original idea for Monopoly came from Elizabeth Magie.

Fig. 5. Word cloud of the main information learnt by MagiePoly participants

In response to the survey, of the non-participants in the game, two thirds expressed interest in playing a future game.

5.2 Skills development

One of the challenges of the interviews was to develop the students' reflexivity to identify the skills they had developed as well as possible improvements.

The skills are different depending on the role of the students in the organisation of the event. The president of the association was able to identify leadership, conflict management, organisation, and communication.

> *It is particularly important for me to make sure that the right information is conveyed, I pay attention to the way things are said, I try to adapt according to the audience. It's not easy!*

The creator of the game was confronted with managing a team, managing time and especially the unexpected.

> *It was stressful because we only had a short time to create the game and there was a lot to do. It's a big investment of time, but I wanted to make sure that the game was created on time as we had imagined it. I was happy to be able to pass on information and exchange ideas on themes that are important to me.*

By realising the survey, the MagiePoly creators have also developed skills in project management while identifying which indicators that could assess the success of their project.

5.3 Future developments

The interview showed that when students carry out projects, for example after the event has taken place, or a project has been handed in for a course, they leave it behind and move on. It is important for the teacher to support the students to reinvest or continue a project that is impactful and important in terms of the values being promoted.

17 people have expressed an interest in helping to improve MagiePoly, and 6 would like to become MagiePoly facilitators.

The planned improvements for MagiePoly are related to the rules, the content of the cards and the given explanations or justifications, the training of facilitators and the sharing of MagiePoly to as many people as possible being inspired by the Climate Fresk (Climate fresk, 2023).

6 SUMMARY AND ACKNOWLEDGMENTS

Many projects are run by students within student associations. In this article, we have tried to show that it can be useful to draw on these student projects, which have all the characteristics of a learning situation in which a student can be committed and persistent in their learning. It is also important to enable students to identify the skills they are developing if they are not aware of them. Students who create projects on their own initiative, if supported and accompanied by teaching staff or the institution, gain confidence, are motivated and reinvest themselves in their studies. It's a step towards academic success.

Elizabeth Magie creates the Landlord’s Game in 1903 with two sets of rules (Pilon 2018). It was a teaching tool meant to demonstrate that the anti-monopolist set in which all were rewarded when wealth was created was morally superior than the monopolist set in which the goal was to dominate opponents. 120 years later, students are paying tribute to her by creating a game to raise awareness about gender inequality. We thank all those who are committed to a more equitable world.

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Communicating complexity to prepare for complexity

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ABSTRACT

A trend in higher education is a stronger focus on the content of a study program as a whole rather than the individual courses that make up the program. The Norwegian university of science and technology (NTNU) has recently completed a large project, *The future of technology studies* (FTS), that attempt to describe how study programs should prepare students for a technological career in a rapidly evolving society. A central recommendation from the project is the necessity of an integrated, program-driven curriculum. Hence, there is a need for a useful description of the content at the program level.

However, a typical description of the learning outcomes of a study program is very brief, often just a set of bullet points that is in no way sufficient to describe the complexity of a study program.

Two study programs in physics and mathematics at NTNU are in the process of revising the study program following the recommendations of FTS. We found that the current framework for documenting the content of the study program is not sufficient. We are proposing a new scheme where the content is documented in a *master document*.

Some new features of the master document that are typically not part of conventional program descriptions are: Specific target audience, not only what but also what not, and why and why not, using a natural language, and maintaining complete revision history.

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1 INTRODUCTION

> - that this *University*, under God, shall have a new birth of freedom — and that government of the *faculty*, by the *faculty*, for the *students*, shall not perish from the earth.
>
> *freely after Abraham Lincoln, Gettysburg address (changes from original in italic).*

We will in this paper present thoughts and work we have done on how to develop a description of the curriculum of a study program that is actually used by faculty when they teach and develop courses in the program. It is our experience that current descriptions of the curriculum are often tailored to fit top-down frameworks and are not useful or actually employed by staff when they conduct their teaching. We believe that a bottom-up description of the program, developed by faculty as whole, is necessary.

1.1 Context

The context of this work is a 5-year engineering program in physics and mathematics (MTFYMA) [1] and a 3-year bachelor program in physics (BFY)[2] at the Norwegian University of Science and technology (NTNU). MTFYMA is a joint program between the Department of physics and the Department of mathematics.

NTNU recently completed a university-wide project titled *the future of technology studies* (FTS) [3]. The aim of this project was to identify the necessary competencies that engineers will need in a future job market, as well as best practices for a modern engineering education. The project resulted in several reports that were synthesized into 10 principles for how programs should be offered, and 12 general competencies that all students should acquire.

To follow up these recommendations, the study program boards of MTFYMA and BFY decided to initiate a revision of the study programs. It was through this process we found the current description of the program to not be sufficient.

1.2 Bakground

The first of the FTS principles states the students should develop "...holistic and integrated competencies.". The sixth principle states that "...the studies should be developed through a program-driven approach" (authors translation). Our interpretation of these principles is that the program should put more emphasis on how the various courses are connected and that the desired competency is built through the sum of various courses. A program-driven approach entails a stronger focus on the overall *curriculum*

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[1] `https://www.ntnu.edu/studies/mtfyma`

[2] `https://www.ntnu.edu/studies/bfy`

[3] `https://www.ntnu.no/fremtidensteknologistudier`. (only in Norwegian)

rather than the isolated courses. It is important to emphasis that in our institution this represents a significant shift from the current culture where individual courses have a very weak connection to the overall program and other courses. The instructor has almost full freedom to adapt courses and the courses evolve primarily in the context of a single course and along the interest of the instructor, rather than the program.

The term *curriculum* can carry different meaning in different contexts. In this paper we will use a broad understanding of the term to encompass the stated learning objectives, but keeping in mind the notion that the actual learning and tacit learning are important aspects of the curriculum (Blackmore and Kandiko 2012). A practical definition provided by Hicks (Hicks 2018) states that the curriculum consists of

1. What is being learnt
2. Why it is being learnt
3. How it is being learnt
4. When and where it is being learnt
5. The demonstration that learning is taking place.

We will build upon this definition later in the paper.

The curriculum that students eventually encounter at a university and the way it is documented are affected by requirements or recommendations from organizations at multiple levels. These organizations can to a varying degree enforce these requirements, through law or incentives, or be limited to publishing reports and recommendations.

At the international level we find as an example the European qualification framework (EQF), which through national legislation (e.g. the Norwegian qualification framework for lifelong learning (NKR)), puts requirements on how the learning outcomes of the program are to be described, and how course workloads are to be quantified (ECTS). NKR requires that the learning outcomes of the program are structured into 1) knowledge, 2) skills, and 3) general competencies. In our institution, in the program description, each of these components are described by a short paragraph and a few bullet points. If one compares the national template with the program description one can see that the program description is very similar to the national template with just generic terms, e.g. *field of study*, replaced by something specific, e.g. *physics and mathematics*.

At the institutional level there may be policy documents prescribing particular learning outcomes or competencies to be achieved by all students at the university. E.g. some currently trending terms are *sustainability competencies* or *digital skills*. Particular programs are then often required to document that they meet these requirements, e.g. by providing a matrix (often referred to as a curriculum mapping) with learning outcomes on one axis and different courses on the other axis and a check mark if the course contributes to the learning outcome. These check marks are highly subjective and the common approach seems to be to search for how the current program can be interpreted to fill the matrix rather than use the matrix to change the current program.

It is our experience that these top-down processes often have negligible effects on the actual program. At the program level the process is more about figuring out how the current program can be claimed to satisfy the requirements rather than creating actual changes in content. This passive approach has a dual negative effect. First there is little actual change. Secondly, the lack of interest at the program level triggers even stronger regulation from the institutional level, and the lack of flexibility might lead to quality reduction at the program level.

We believe that there are several effects that contributes to this lack of response from faculty. First, the requirements can be very general ("more active learning", "solid sustainability skills") and seem far removed from the core content of the program and the expertise of the faculty. Often a very syntetic language is required when stating the learning outcomes. E.g. *at the end of the study program the student should be able to [some active verb] [some overarching concept]*. This use of language which is very different from how faculty typically discuss their own subject matter, also contributes to faculty distancing themselves from the top-down approaches to curriculum change. Second, usually few or none of the faculty have been involved in developing these requirements and it is difficult to grasp their content without having been part of the development.

There is also a cultural aspect where in the past, professors have been given complete freedom to control content and delivery of courses and are reluctant to relinquish this right.

The result is that all documentation that describes the content a program and its individual courses are top-down, and with little engagement from the faculty. This results in a very weak connection between the description of the curriculum at the program level and the content of the individual courses.

1.3 Proposed solution

What is missing is a documentation of the curriculum of a program that is written for the faculty by the faculty. The key feature being that this documentation of the curriculum is not written to appease some quality assurance body but to generate a, primarily internal, understanding of what are the goals and learning outcomes of the given program. We believe this to be essential to realize a "holistic and integrated" program.

The documentation will also be relevant for external stakeholder professionals, making it easier to offer concrete advice on what could be improved in a given program. It is easier to provide feedback on concrete descriptions rather than general, overarching principles.

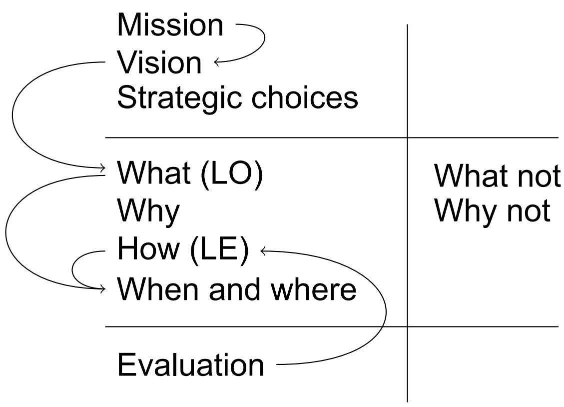

Fig. 1. Sketch how the main components of the master document and how they are connected. We believe that a documentation of this parts are necessary to have a complete description of an integrated curriculum.

The document should also provide clear documentation of the connection between the learning goals and content of the individual courses. This requires that the learning goals are sufficiently detailed and organized in some sort of hierarchy to be manageable.

This document should be the governing description of the program. In the following we will refer to this as the *master document*. Any other descriptions of the program and courses, e.g. to adhere to quality assurance requirements or similar, are to be derived from the master document.

2 METHODOLOGY

2.1 The master document

The previous section introduced the need for a document that describes the content of the study program, aimed at the people that actually provide the program. The main goal of the *master document* is to communicate to the faculty and external professional stakeholders, the curriculum of the study program. Notably, students are *not* a primary target audience for the document. The document should be available for students, but other ways of communicating the curriculum to students might be more appropriate.

Fig. 1 illustrates the main parts (chapters) of the master document that we believe are essential to document. First, the program must have a clear *mission* to meet some need in society or for the individual. Without a clear idea of this, further work is difficult. A *vision*, which is an overarching description of the learning outcomes of the study program, documents how the program target the needs described in the mission. The actual learning outcomes (LO), are derived from the vision and describes *what* competencies the student will acquire. The LOs must be sufficiently detailed to inform *how* the learning experiences (LE) should be designed. For a 5-year program this will result in a large amount of LOs and a sensible hierarchy will be necessary to provide sufficient overview the program. Every LO should also be accompanied by a reason for *why* it is included. When future revisions need to prioritize what should be included and not, it will be very valuable to understand why something was included in the first place. Once the what (LOs) and the how (LEs) are in place one can determine *when and where* in the study program these should be developed.

We believe that an almost equally essential feature is to also describe *what not* to inlcude in the program and *why not* this has been prioritized. Explicitly stating what is not to be included can create a clearer boundary for the content of the program. This should then be accompanied by the reason for not prioritizing the content. We believe that this is important to avoid courses becoming bloated with too much content. This will invariably lead to more superficial learning. This effect is own seen when new instructors each add additional content they find interesting. The teaching at our institution is often described as *fire-hose pedagogy* which is quite descriptive.

The program must also be evaluated. This evaluation serves two purposes. The first is to ensure the qualification of the candidates (summative assessment). The other is to assess the quality of the LEs. It is essential to document and have a collegial understanding of both these aspects. With regards to the summative evaluation it is well known that it is a very strong driver for the learning environment and the students behavior. The assessment method will therefore have significant implications outside an individual course. To assess the effectiveness of the LEs it will be necessary to have some consistency in the assessment tasks over multiple semesters. An example of such an organized evaluation scheme is the Research and evaluation framework (Kelder, Carr, and Walls 2017). Formative assessments are included as part of the LEs.

We have also included a part named *strategic choices*. These are choices for what is included and how the program is organized that is not strictly driven by the mission but rather by external constraints, regulations, existing culture, historical identity, political issues and so on. These are equally important to document so that future program leaders understand why certain choices are made and can modify them accordingly if external factors change.

For this document to be a useful and living document we believe it should be guided by certain principles and aims:

- Foremost, the document should develop by and for the main users of the document which is the faculty/instructors. To this end it should be written in a language and in a format that is appropriate for this target group.
- Secondly, it should be informed by the main stakeholders in the curriculum, that is, employers and students.
- It should be sufficiently detailed to be able to describe connections between the what, why, how and where (as described above), but also not grow so large that it is unmanageable.

- The document should be *informative*, i.e. it should state non-obvious choices and priorities. E.g. in the current program description, the first statement is “The students should have a solid foundation in physics and mathematics”, which is not very informative for a study program in physics and mathematics.
- An important aim is to inform new staff about the mission of the program as well as the teaching and learning culture.

Even though the document is developed by and for faculty it should not reside in some ivory isolation. It will be the role of study program managers to bring in input from external stakeholders and reports and translate this information into a language that is meaningful to and can be integrated by the faculty of the given program. Similarly study program managers will have the role of translating the master document into other formats to adhere to the various mandatory quality assurance systems.

2.2 Development

We believe that a key factor for making a document that is actually used is that it is also *developed* by the faculty, for the faculty. For the study programs MTFYMA and BFY there is about 100 scientific staff across two departments (mathematics and physics) that contribute to the courses in the program. In addition there is about 200 temporary staff (PhDs and PostDocs) and 650 students. Not to mention external stakeholders (industry) and university management. How can we engage such a large group in the development of the master document in an efficient way? Sending around a Word-document with track changes enabled is a recipe for disaster. Such a large scale involvement has been described as Participatory curriculum development (Taylor 2000). A limiting feature has been noted to be appropriate meachnisms or tools for such large scale involvement (Alexander and Hjortsø 2019).

Luckily there exists technology for organising large scale contributions to text. In the realm of programming, *version control systems* (VCS) have been developed to enable hundreds of programmers to work on the same code simultaneously, and ensure that nothing is lost when changes are made. Even though the technology is not designed for working with prose, we belive that it will work quite well for this purpose as well.

The branching technology of version control systems enable multiple groups to work on multiple parts of the document at the same time and changes will (usually) be seamlessly integrated on merging the various inputs. Another valuable aspect of version control systems is that a complete revision history is maintained so that it is always easy to go back and look at what the document said 1 day or 10 years ago.

Our current plan is to divide the development of the master document into subprojects where each subproject works on a separate topic of the curriculum and the documentation is developed in a separate branch in the VCS. The method of engaging faculty might vary (e.g. hearing, working group, seminar, etc.) but for any such process the result should be a suggested modification to the master document that is proposed through the VCS

We are currently using *git* as a version control system and *github* as a central repository for the master document. The document can be found at `https://github.com/maglil/mtfyma-bfy`. Unfortunately the document is currently only in Norwegian but we are exploring how we to efficiently also maintain an English translation to ensure international bench-marking of the program.

The version control system requires that the encoding of the document is a pure text file and we are currently using LaTeX as a markup and typesetting system.

3 RESULTS

We have not yet tested the idea of a master document in large scale editing procedures, however we have presented the idea of the master document in our preparation for a revision process. To initiate the revision process we needed to ensure support both at the management level (head of department, dean) as well as among faculty. The management level was positive to the idea of a detailed description of the program and that the document was sufficient to indicate that we were working on generic skills (collaboration skills, sustainability skills) but translated and organized in a way that is more meaningful to staff.

We have also conducted meetings with all the research groups at the two departments (12 in total) where we proposed the idea of documenting the content of the program in a master document. Even though many of the staff provided very clear opposition to many of the ideas for how to change the program, none voiced any objections to the idea of having a document that describes the content of the program. Quite on the contrary, many relayed anecdotes of how they had been given responsibility of courses but without any information about who the students are, what the learning outcomes where or how it related to other courses.

To start the engagement of the staff we conducted two seminars where we worked on a proposed description of experimental and digital skills. From a program manager perspective we found it very efficient to send a particular version of the master document as a base for the seminars and then being able to revise the document based on the input using multiple branches in the version control system so that multiple people could work on the document on the same time.

3.1 Conclusion and future perspectives

So far we have had positive experiences with the concept of a *master document* as presented in this paper.

However, we have not yet started the real work of engaging multiple working groups to work on the document in tandem. There is also the open questions of how the faculty will actually use the document in their planning of teaching once the document is finished.

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LEARN AND WORK, A HYBRID EDUCATION MODEL FOR ENGINEERING EDUCATION

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ABSTRACT

Traditional models of education are undergoing significant change in recent times due to evolving graduate attributes, shaped in no small part by the changing demands of modern industrial practices. Technology is one of the key elements of the factory of the future. Advances in manufacturing and digital technologies facilitate automation and offer significant benefits in a variety of areas.
Academic programmes that feature industrial work placement have long been a feature of engineering education in TU Dublin. The BSc in Process Instrumentation and Automation is a three-year programme that goes further in that it evenly balances on-campus instruction with work placement. The programme was specifically devised in response to industry feedback that had identified significant skills shortages in the areas of industrial instrumentation and automation. It is a hybrid between the apprenticeship model of education (www.apprenticeship.ie) and the traditional engineering degree model and directly addresses industry's immediate need for experienced graduates.
Participation in the programme is sponsored by Irish Medtech Skillnet, a learning network for companies in the medical technology and engineering sector that responds to the training needs of that sector.
This is one step in the lifelong learning path of a modern graduate.

This paper will provide a detailed critical review of the ‘learn and work’ model; strengths, challenges and opportunities offered by this mode of engineering education.

1 INTRODUCTION

1.1 Background

Process instrumentation and automation technicians are employed in large chemical, pharmaceutical/biopharmaceutical, food processing, oil and gas, waste-to-energy conversion facilities and manufacturing plants. Their principal roles cover installation, maintenance, and calibration of measuring instruments. This role is key in that it provides the technical support that is essential to a high-tech manufacturing process. These technicians require training that is specific to automation processes across a range of industries. This paper provides a critical review of the Level 7 (www.qqi.ie) Process Instrumentation and Automation (‘learn and work’) Programme; the graduates of which, work as qualified instrumentation and automation technicians. The programme was specifically devised in response to industry feedback, with pre-programme validation confirming significant skills shortages in the areas of instrumentation and automation (EGFSN 2013).

This programme is a hybrid model, lying somewhere between the apprenticeship model and a traditional engineering degree programme, in that it evenly balances academic modules with work-placement. Apprenticeship is a programme of structured education and training that formally combines and alternates learning in the workplace with learning in an education or training centre. The employer pays the apprentice for the full duration of the apprenticeship, and it typically leads to a level 6 qualification. Currently in Ireland there is a backlog in the apprenticeship sector, leading to long qualifying times for apprentices. This ‘learn-and-work’ model ensures completion of this BSc programme within a fixed 3-year period.

It is well documented that work-based learning programmes make valuable contribution to the third-level educational experience (Sheridan and Linehan 2011). Studies have indicated the advantages of integrated work placement in benefiting students with different skills, for whom the inductive pedagogy (from experience to theory) is more efficient than the classical deductive one (Rouvrais and Remaud and Saveuse 2020).

2 PROGRAMME STRUCTURE

The programme is structured over three academic years and runs through the summer, the students earn 180 ECTS credits in total, 60 per academic year. First year students spend their first 2 semesters studying taught modules in the university and then spend the summer in work placement. Students on year two and three spend their first semester on campus and their second semesters and summers in work placement. See details in Figure 1. This structure has evolved over the course of delivery of the programme in response to industry and student feedback, with more focus now in first year on academic modules and in fully preparing the student for work placement.

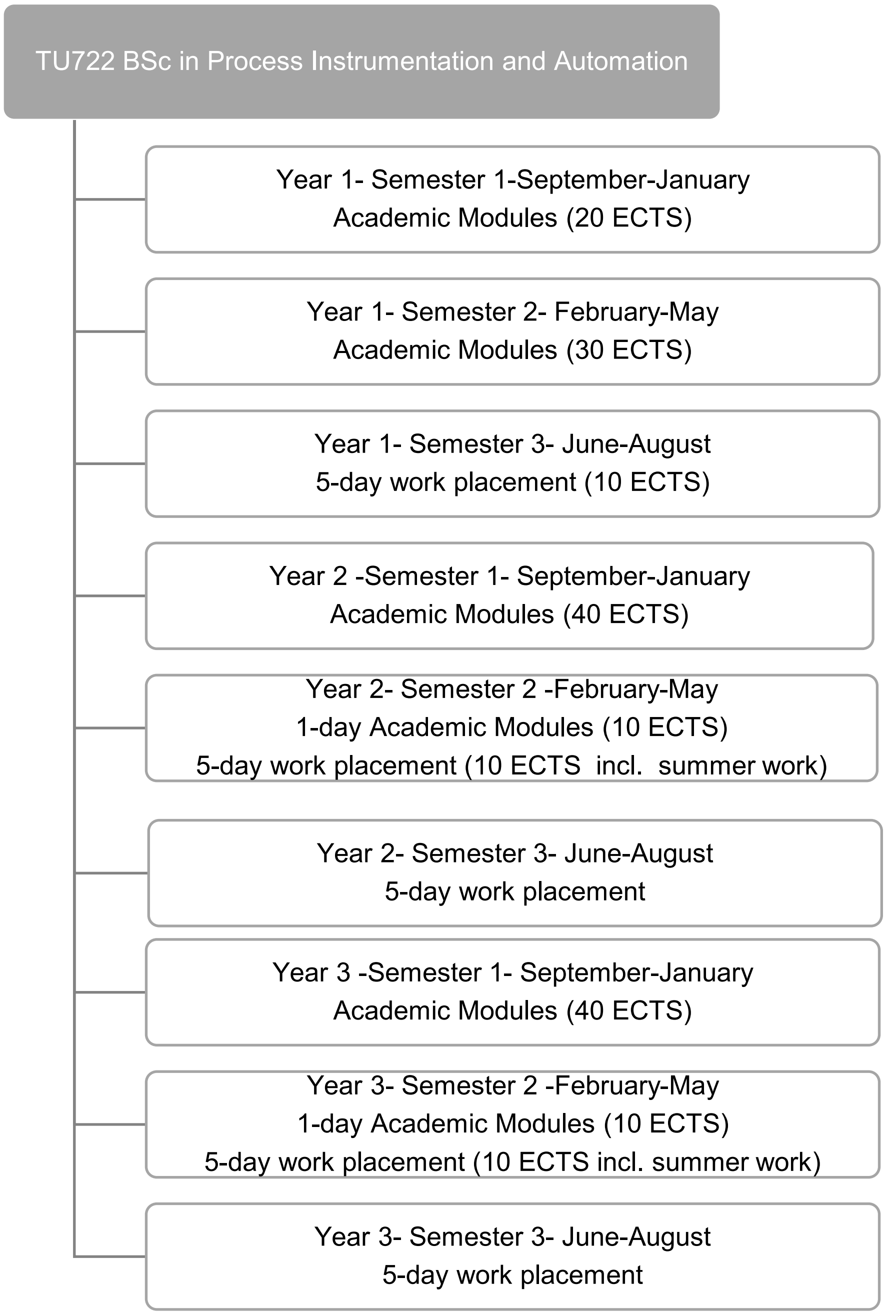

Fig. 1: Structure of the Programme

Typically, the 5-day week academic blocks comprise about 24 hours/week in the university. This is broken down into $^{2}/_{3}$ lab work and $^{1}/_{3}$ lectures. This balance of classroom learning, and practice-based lab work suits the learning style of the students on the programme. In addition to this, students have laboratory reports/case studies to complete or self-directed learning to carry out, to consolidate learning.

3 STUDENT RECRUITMENT TO THE PROGRAMME

Since 2020, students are recruited through the CAO (Central applications office) (www.cao.ie). The Central Applications Office processes applications for undergraduate courses in Irish Higher Education Institutions (HEIs). Decisions on admissions to undergraduate courses are made by the HEIs who instruct the CAO to make offers to successful candidates. CAO points are calculated based on student's grades in state examinations. The Irish school programme on which the points are based is known as the Leaving Certificate. Points are calculated based on 6 subjects, with maximum points of 625 achievable.

Prospective candidates must also meet several other minimum entry requirements as detailed in Table 1. The required points for admission to this programme are a combination of the CAO points in addition to a combination score from interview and aptitude test. This year, 2023 the entry requirements were simplified, as they were perceived to be a deterrent to students applying for the course. As a result, requirement numbers 4 and 6 (Table 1) were removed. The effect of removal of these additional requirements will be evaluated in September 2023, when applicant numbers are reviewed.

Table 1: Minimum Entry Requirements

<table>
<tr><td>No</td><td>Entry Criterion</td><td>Minimum requirements</td><td>Notes</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Leaving certificate/CAO points</td><td rowspan="2">5 subjects pass (40%) to include a minimum grade of O6/H7 in both Mathematics and either English or Irish</td><td>H7:30-39% at Higher Level</td></tr>
<tr><td>O6:40-49% at Ordinary Level</td></tr>
<tr><td>2</td><td>Aptitude Test</td><td>Minimum score of 42/100</td><td rowspan="2">Combined score of 110/200</td></tr>
<tr><td>3</td><td>Interview</td><td>Minimum score of 50/100</td></tr>
<tr><td>4</td><td>Ishihara colour vision test 24 Plate Edition</td><td>Pass</td><td>Criterion removed for 2023/24 entry</td></tr>
<tr><td>5</td><td>Submission of a Résumé</td><td>Submitted prior to interview</td><td></td></tr>
<tr><td>6</td><td>Submission of 2 written references</td><td>Submitted prior to interview</td><td>Criterion removed for 2023/24 entry</td></tr>
</table>

Recruitment has proven to be challenging and labour intensive. Despite extensive engagement activities such as apprenticeship fairs, school visits, taster sessions for schools and engagement with FET (Further Education and Training) centres (www.fet.ie), numbers of applicants remain low. Perceived reasons for the low numbers of applicants are detailed in Table 2.

Table 2: Perceived barriers to recruitment to the programme

1	New and unfamiliar programme of study	Word of mouth is beginning to positively influence numbers of students applying to the programme as more graduates from the programme enter the workplace.
2	NFQ (www.nfq.ie) Level of the programme offering	Perception among CAO applicants that Level 8 is a more attractive choice.
3	Marketing issue	Rebranding of the programme title may be required to include the word "engineering" or removing the reference to "learn and work": this is currently under discussion.
4	Additional entry requirements	The additional entry criteria: aptitude test and interview may be a deterrent to potential students who may be busy with Leaving Certificate studies.

Current students participate in recruitment events and have shown themselves to be excellent role models for the programme. Industry partners assist with the recruitment of new students to the programme by promoting it at school events and sometimes they themselves propose students for the programme.

3.1 Entry Criterion-CAO points

To date there has been a large variation in the CAO points achieved by the student recruits as seen in Figure 2. These range from 152 to 523.Even with this large variation in Leaving Certificate results, students from all base levels are successfully completing the programme. The mixed levels in the classes may have the effect of raising the standard of those students who entered on lower points (<400).

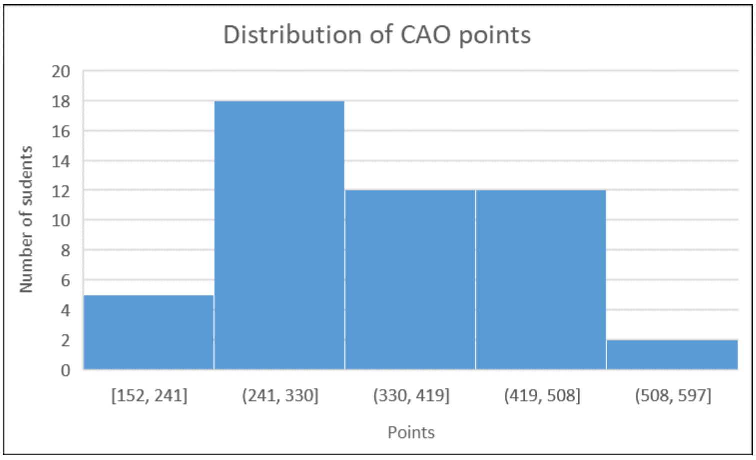

Fig. 2: Distribution of CAO points

3.2 Entry Criterion-Aptitude Test

Prospective students are invited to take an aptitude test prior to being called for interview. Aptitude tests are proctored and are hosted online by a third-party company. The test consists of 28 questions that are taken over 45 minutes and is based on four main question areas; abstract reasoning, numerical ability, analytical ability, and data analysis.

The aptitude tests have yielded some valuable trend information to date, for example lower scores in the abstract reasoning section of the test seem to correlate with those students who struggle more with the academic content of the programme.

3.3 Entry Criterion-Interview

This is a key step in the selection process; students in traditional engineering courses have the benefit of at least 3 years in university in which to gain confidence and maturity before embarking on work experience, whereas these students need to be work-ready at the end of their first year. The interview provides the opportunity to assess whether the student would be a suitable fit for the programme. The format of the interview is usually via an online meeting with 3/4 staff members. The candidate is asked to discuss various details on their résumé, particularly in relation to subjects studied and interests. The level of research and preparation that the student has carried out is often a good indicator of the level of interest that the student has in this programme. Practical details such as mode of transport to work placement as well as general demeanour and attitude are also considered. Prospective students have an opportunity to ask questions and are therefore more informed around what to expect. They are also inclined to do some research on the programme in preparation for interview and this leads them to making a more informed career choice. This year to date, 2023, approximately one quarter of the candidates interviewed had heard about the course through word of mouth. This is an encouraging figure, as more students graduate into well paying, satisfying employment this will enhance the reputation of the course. The interview process provides valuable additional information, such as how the candidates heard about the course or why they chose it.

4 WORK PLACEMENT REVIEW

Research has shown that the inclusion of work placement in the curriculum can strengthen university–industry collaboration and can help to shape engineering curricula based on feedback from students and industry partners (Carbone et al. 2020). At the programme's inception, a range of potential industry partners were invited to meet with academic staff to discuss the structure and content of the programme. Feedback indicated that placements of length 6 months or longer were deemed to be more useful from an industry perspective.

Studies also show that work-based experience results in higher post-graduation starting salaries and enhance the likelihood of securing a job offer prior to graduation. These results are borne out in this programme with most students securing a job offer prior to graduation. However, some studies show that an improvement in academic results are only marginal (Purdie et al. 2013). Future review of the programme will examine the grade progression of students on the programme to assess the effects of work placement on their overall academic performance. Informally, the positive academic progression of many students is evident as they mature through the programme. Work-placement enables students to learn how an organisation functions and how their work can contribute (Vaezi-Nejad 2009). As there are limits to scale for work related internships or placements, other forms such as field trips and site visits are common in engineering curricula. These have been shown to expand students' perceptions of their career work and identity (Carbone et al. 2020). Few programmes offer work placement opportunities to match this one in duration so the benefits such as an “increase in agency and a contextualised learning experience” are likely to be higher (Purdie et al. 2013). Studies also show that work placement has a “positive impact on students’ self-efficacy, and in articulating their skills and strengths” (Edwards 2014).

Industry placement periods are significantly long and so lead to deeper learning and immersion in the everyday work that is carried out in a manufacturing facility. This is differentiated from a short-term placement that may be more superficial in nature and allows for greater integration of the student into the engineering team from the first year on the programme.

5 WORK PLACEMENT ARRANGEMENTS

One member of the programme team acts as the work placement co-ordinator and all communication with the industry partners are directed through them. Industry partners were initially recruited through the programme team’s professional contacts and these industry partners also went on to recruit other companies on behalf of the programme. The partners work with the programme team on an annual basis taking one or two students from each year on the programme. In a small number of cases, students have secured work placement themselves, this typically happens in third year when students have more experience. Students have successfully approached companies directly using LinkedIn and email.

Industry partners were involved in pre-programme validation and are regularly consulted on the efficacy of the course delivery.

Regular contact is maintained with the industry partner at the start, middle and end of the placement for each student. Pre Covid-19 this was achieved through visits from the placement co-ordinator, but increasingly this is achieved through online meetings and phone calls.

5.1 Industry recruitment of students from within the programme

Matching students with industry for work-placement is achieved through a round of interviews with the industry partners. These interviews typically take place in December /January and the industry partners often deliver a presentation outlining what they do, to the student group. The work placement co-ordinator then provides the industry partner with a selection of résumés that allows them to shortlist candidates and call them for interview. The co-ordinator endeavours to place students in work that is geographically suited to the student and consideration is given to whether the student has access to their own car. Interviews take place either online or in person, at the university or on-site and are arranged directly between the student and industry partner. Ideally, offers to students are made through the programme co-ordinator. Students will, in general, remain with the same placement company for each of the three years of the programme.

In a small number of cases, it can be difficult to place a student, where they do not meet the employer's expectations at interview. This has generally been shown to be related to poor student communication skills. In this instance the programme team may rely on the goodwill of an industry partner to provide a placement opportunity. Consequently it has been found that work-placement enhances that student's skills and progression opportunities.

Studies on the primary motivation of the employer for becoming involved with programmes such as this one, include social duty, the opportunity of training students in company needs and as a source of fresh staff recruitment. Studies also show that less rated motivators were improving the company's position within the sector, benefitting from university services, and saving time in recruitment (Ferrández-Berrueco and Sánchez-Tarazaga 2021).

Future work on this programme will seek to identify the motivating factors of the employer but informal discussion with employers highlights the skills shortage as the primary motivator.

5.2 Preparing for work placement

First year students are prepared for work placement in several ways. Academic modules incorporate critical skills such as effective communication, technical report writing, presentation skills, résumé and interview preparation, software proficiency skills, concept generation, group dynamics and teamwork and basic project management skills.

Prior to going on their first placement, informal information sessions are facilitated in the university to enable first years to learn from the experience of those students who have already participated on work placement with a particular company. These sessions are also designed to allay any apprehension that first year students may have. Students complete an industry induction on their first day and then in general they work as part of a team where they effectively shadow qualified technician(s) on site. Students also undergo extensive in-house training while on placement. Future review of the programme will involve student surveys to assess the student experience.

5.3 Assessment and challenges

There is consensus on the limits to scale of work placement activities and this programme is no different in that respect (Carbone et al. 2020). However, the rewards that are borne out in solid employment offers at the end of the programme for each student warrants the time and effort that is expended in the organisation of the work placements. Most students have secured an offer of employment with their placement company before they complete the programme.

Assessment of work placement activities generates much discussion and has been widely studied. Monthly logbooks, industry supervisors report and student final report and presentation are used to assess work placement. Logbooks are graded using a rubric based on the module learning outcomes. Weekly entries encourage students to detail what they have been working on and have learned that week. An evaluation section prompts self-reflection in terms of progress made and in identifying areas for improvement. Logbooks allow the student to record learnings and methods of work for future reference and this practical knowledge enhances understanding of key concepts. It provides the academic staff with valuable insights into the development of each student on an ongoing basis. Employer feedback is garnered through an MS form, a Likert scale is used to assess student performance in 15 key areas. Employers are also prompted for general feedback. The Covid-19 pandemic caused some additional difficulties during 2020/2021, most students were allowed to continue or to work from home. A small number of industry partners opted out of taking a student during that time. This was addressed by condensing the work-based learning modules into two 3-month terms on an exceptional basis.

There are occasional operational challenges, for example when offers of work placement are made directly from the industry partner to the students (without consultation with the work placement co-ordinator). This can sometimes cause issues; where a student has already been committed to another placement company by the placement co-ordinator. On rare occasions, students may request a change of placement mid-programme where they feel they are not gaining as much experience as they would like or for other reasons. This is accommodated where possible. There is a fine line to tread to maintain a good relationship between all parties. This is one of the main challenges for the work placement co-ordinator.

6 RESULTS

The most significant challenge faced by the programme team is attracting students to the programme. The perceived barriers to recruitment are under consideration and are being addressed on an ongoing basis by a more proactive recruitment drive and a considered review of the admission criteria. The candidate-selection process is very resource intensive in terms of time and university personnel.

All graduates of the programme are in full employment. Feedback from Industry partners cite typical starting salaries of €37,000-€47,000 being achieved. Career progression is fast-moving with students earning upwards of €50,000 after two years. This compares very favourably with similar programmes, for example a graduate engineer who has spent 4 years in university can expect to earn €36,000 (Engineers Ireland Salary Survey 2023).

Retention rates on this programme are higher than similar level 7 engineering programmes. To date the average completion rate on the programme of 84.7%

(Table 3) compares very favourably with national overall completion rates of 60% in other level 7 engineering programmes (Pigott and Frawley 2019).

Table 3: Student Completion Rates

Intake Year	Number students started	Number complete/ on-target to complete	Number student losses	Completion rate %
2018	10	9	1	90
2019	15	13	2	86.7
2020	9	7	2	77.8
2021	12	10	2	83.3
2022	14	12	2	85.7
Total	60	51	9	
Average				84.7

These high completion rates are at odds with the findings of Higher Education in general where ”There is a strong positive correlation between the proportion that enter with up to 400 Leaving Certificate points and the non-completion rate, indicating that lower points are associated with higher non-completion rates.” 96% of those students who do not complete their level 7 engineering programmes have <400 CAO points (Pigott and Frawley 2019). It has been shown that there are “relatively high rates of non-completion in the computing and engineering, manufacturing and construction fields of study, particularly at levels 6 and 7” (Pigott and Frawley 2019). The recruitment process is believed to contribute to the higher retention rates being achieved. In addition to this, small class sizes (<16 students) allow for more individual attention and facilitate practice-based learning. Unlike other comparable Level 7 engineering courses where large class sizes can sometimes lead to anonymity and dissociation, smaller numbers can have a stabilizing effect and problems can be identified and addressed more quickly. The practical mode of delivery is beneficial in that students remain engaged through hands-on practice-based learning. Work placement blocks allow the students to put their learnings into practice, this appears to lead to greater engagement in the academic material. Studies also show that work-based learning benefits the student in a “variety of other ways, particularly reduction in anxiety, increases in agency and confidence” (Purdie et al. 2013) which may also contribute to the higher retention rates.

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SUPPORTING WOMEN IN ENGINEERING & TECHNOLOGY THROUGH A COLLABORATIVE PRACTICE AND SUPPORT NETWORK USING TARGETED INTERVENTIONS

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ABSTRACT

Despite ongoing efforts to recruit and retain women in third level engineering programmes in Ireland, there is still a lack of diversity in these programmes with typically fewer than 20% of students being female. This paper will describe the evolution of a female focused university wide network called WITU (Women in Technology United), which aims to retain female students in engineering and technology programmes, and to increase the number of gender minorities coming onto these programmes. It is also a response to the Sustainable Development Goals, particularly, SDG 4 (quality education), and SDG 5 (gender equality), and addresses actions highlighted in a recent Athena Swan review in our University. The network was formed in 2020 and extended to become University wide during lockdown, which in itself presented specific challenges.

This paper describes the activities of the WITU network which runs events and celebrations for female students on our engineering and technology programmes such as ‘Meet & Greet’ events for incoming year one students, scholarship workshops, coding camps and International Women’s Day celebrations. The events are run collaboratively with students, academics and employer networks, with participation from recent female graduate role models, who are contributing to the wider engineering community. This paper describes these events and their impact on participants. Outcomes and feedback from participants show the critical role of these types of targeted interventions in supporting women and gender minorities and address some of the most pressing global challenges relating to the above-mentioned SDGs.

1 INTRODUCTION AND BACKGROUND

Gender inequality exists in science, technology, engineering and maths (STEM), not because of a lack of talent or ambition, but because of barriers and culture, that means talent is not always enough to guarantee success. The importance of connections built through support networks is highlighted with successful strategies and mechanisms to improve the attraction, access, guidance, and retention processes for women in STEM (García-Peñalvo et al., 2022). In an effort to overcome gender related barriers and improve career outcomes, these networks provide support, mentoring and networking opportunities, from second to third level education and throughout their careers. Bringing people together to share experiences and demonstrate support and leadership is an essential aspect of building a culture of inclusiveness (“CWIT - Connecting Women in Technology”, 2023; “I WISH”, 2023; “Women in Science and Engineering Research, WiSER”. TCD, 2023; “Women in Technology and Science IRELAND”, 2023). The WITU network in TU Dublin was established in 2020 in direct response to identified challenges around increasing gender diversity within engineering and technology fields. This paper explores some of these challenges and describes how WITU operates as a collaborative pan University network to achieve its goals and describes the impact that targeted interventions have had on participants.

Ireland is rated seventh on the EU-28 Gender Equality Index, scoring 74.3 in 2022, compared with an average score of 68.6 (European Institute for Gender Equality, 2022). The index measures gender gaps between women and men in six domains; work, money, knowledge, time, power and health. However, despite Irish women being more likely to have a higher education qualification than men (43.2%F compared with 40.7%M) (Central Statistics Office, 2017), there is still a dearth of women in STEM disciplines (Tomassini, 2021). On a global level, the evidence shows typically 8% of women choose courses in engineering, manufacturing and construction and 3% choose courses in ICT (UNESCO, 2017). An Irish HEA report from 2021 found 21% of ICT students were female (Higher Education Authority, 2021), while in the EU it was 19% (EUROSTAT, 2021). This translates to only 11.3% of engineers working in industry (Kent Doyle, Costello and Kopacek, 2019). The attrition of women in engineering courses and in industry has been labelled as "the leaky pipeline" (Kent Doyle, Costello and Kopacek, 2019) and it is recognised that attrition occurs at multiple time points along a woman's engineering career.

The significance of STEM education for economic growth and innovation, especially in engineering and technology, is increasingly acknowledged (Dunne at al., 2022; Ribeiro at al., 2023; Croak, 2018). This has resulted in augmented investment in education and research in these fields, alongside initiatives to promote diversity and inclusion. Historically, reasons identified which have discouraged women from pursuing careers in STEM include societal biases, gender stereotypes, lack of self-efficacy, lack of access to resources and mentoring, and an unsupportive environment (Lester, 2010; Kordaki and Berdousis, 2020). To counteract this, it is important to highlight the many reasons why women should pursue careers in engineering and technology. These fields can be intellectually challenging and rewarding, providing opportunities for personal and professional growth. They offer opportunities to be creative and innovative, as well as to solve complex problems with critical thinking and analytical skills. Additionally, contributing to society with high flexibility can be particularly attractive to women who prioritise work-life balance or have caregiving responsibilities and are interested in making a difference in the world. Encouraging women to choose these fields is critical to achieving gender equality, eliminating the gender wage gap, promoting financial independence, and ensuring that diverse perspectives are represented in solving the world's most pressing problems.

Women's under-representation in STEM is an untapped talent, and one needed to meet our commitments for sustainable development, as women are key players in crafting solutions to improve lives (UNESCO, 2017). Thus, Higher Education Institutions have a critical role to play in the implementation of measures to recruit, retain and thus reduce the gender gap in STEM (García-Peñalvo et al., 2002; UNESCO, 2017). Further, a multi-faceted approach that includes the education sector, employers, and policymakers is needed. By promoting equal access to STEM education and resources, challenging gender stereotypes and biases, and supporting positive role models, we can work towards achieving gender equality in STEM. As a network within a third level institution, WITU is establishing links with primary and secondary education institutes and also with industry, and is a point of contact on issues relating to gender. According to the SDG report on graduates in STEM fields (SDG Index and Dashboards - Global Report, 2021) the long-term objective is to 'leave nobody behind' and obtain a female share of STEM graduates of 50% in Ireland. The ethos of inclusivity underpinning the WITU aims, as set out below, is directly in line with this national objective. The creation of the WITU network grew out of a need to address our commitments to the SDGs (particularly SDGs 4 and 5) and at a more local level, the outcome of the Athena Swan review undertaken as part of the University strategy (Higher Education Authority, "Athena SWAN Charter", 2015).

2 METHODOLOGY – AIMS AND SCOPE OF WITU NETWORK

The aim of the WITU network is to retain students in engineering and technology courses, increase gender diversity, and create pathways for all ("Women in Technology United (WITU)". TU Dublin, 2023; "SDG Goal 5 Gender Equality". TU Dublin, 2023) To achieve this, the network implements targeted interventions such as hosting events, creating a support network for students, reaching out to schools, and promoting Equality Diversity and Inclusion (EDI) in technology on social media. WITU collaborates across three campuses, nine schools, and eleven disciplines ("Women in Technology United (WITU)". TU Dublin, 2023).

WITU operates collaboratively through its working group of 41 members who are representative of engineering and technology programmes in the University. Communication among members is conducted through a Microsoft Teams channel, while communication with STEM students is through email, Instagram, and LinkedIn. WITU has marketing strategies to raise awareness of the network among students, which includes a WITU website page and social media accounts. The Instagram page has been a focal point of communication with industry, with companies making contact through it. WITU engaged the services of a graphic designer who designed a branding suite for WITU. Events and initiatives being held across multiple campuses are unified under the WITU banner, with consistent advertising and design employed for posters, invites, social media notifications using the WITU branding.

The events organised by WITU bring together gender minorities, so there is a space created where they can connect with students and alumni in STEM and become part of a larger network. These connections can last throughout their college lives and the sense of belonging generated can encourage them to complete their studies. The next section describes each of these targeted interventions and the feedback and impact from each.

The WITU network is aimed at students on STEM courses, and results of an analysis of the percentage of female students in engineering and technology programmes in TU Dublin is given in Table 1. The data reflects the national and European landscape in terms of the low numbers of female students on technology and engineering programmes.

Table 1. % Female Students in Engineering and Technology Programmes in TU Dublin

TU Dublin % Females	2018/2019	2019/2020	2020/2021	2021/2022
Engineering Programmes	10%	11%	12%	11%
Business Technology	26%	28%	31%	23%
Computing Programmes	14%	16%	17%	23%

3 INTERVENTIONS AND IMPACT

This section describes some of the key activities organised by the WITU network and the feedback of and the impact on the participants.

3.1 Interactive Design Workshop

The online Interactive Design Workshop for female students in technology and engineering programmes was the first pan-University event organised by WITU, aimed at expanding the network across the university and creating connections among students. The project was funded through the 2021 EDI Fund and involved a panel of speakers who discussed gender and diversity in design, including topics such as artificial intelligence (AI) and bias in data, gender inclusivity in industry, and universal design considerations. Students worked in teams on a design challenge, with a key criterion being to explore universal design solutions. A total of 44 participants, including 24 students from various technology disciplines, attended the event. A panel of judges provided feedback on the design solutions, with participants also invited to provide feedback which included some of the following observations.

Participants enjoyed the interactive nature of the event and how the presentations in the first part linked with the design challenge in the second. They noted that the event was insightful and found it interesting to learn about issues around gender bias in technology design. They enjoyed interacting and ideating with students from other programmes and disciplines within the design teams, and found that this enabled them to expand their contacts. In addition, working in teams to ideate, problem solve and present their solutions, helped develop their communication and teamwork skills. Participants highlighted the importance of seeing and understanding different viewpoints when designing, and acknowledged that this gave them a different perspective and understanding of products and technology that are commonly used. They recognised issues around coding and bringing unconscious bias into technology design such as in AI systems. They reported that the event increased their understanding of universal design, and the importance of the user experience in design.

Feedback suggested that the majority of respondents (86%) would be interested in further events, in particular around universal design, events creating awareness around technology, engineering, and design, and with a focus on redesigning women's products that may traditionally have been designed from the male perspective. There were also suggestions for other events including focused graduate recruitment and how women cope and succeed in technology and engineering communities. Ten participants also expressed interest in being part of a focus group exploring the experiences of gender minority groups in engineering and technology programmes. This is planned as a future WITU initiative. In addition, 71% of participants noted that they would be interested in being an ambassador for their programme, and 71% were interested in joining a student-run society for women in STEM.

On asking participants how they thought greater gender diversity can be achieved in our technology programmes in TU Dublin, their responses included:

- Increase number of technology related subjects and workshops in all-girls schools
- Create an impression from a younger age by holding workshops such as this for students in 1st – 3rd year in secondary school
- That they themselves are role models to the younger generation and should spread awareness of design and promote STEM
- Increase advertising for networks such as WITU and the work being done
- Visit schools and talk to younger girls about opportunities available

- Encourage women to study STEM at a younger age
- Educate people in a fun and engaging way, like this event
- More events like this with diversity in speakers and scenarios and create awareness at a younger age
- Encouraging successful women to express themselves to younger generations

The event celebrated women in technology and was a reflection of the importance of gender diversity in technology design. Although it targeted female students, the event was open to all genders to be inclusive and increase awareness around the issues discussed. This finding guided the organisers in their approach to subsequent events in terms of who is targeted and invited.

3.2 Annual 'Meet & Greet' Event for Incoming Year 1 Students

WITU hosts an annual "coffee morning" event as part of the first-year induction for all female students in technology and engineering programmes. The event provides an opportunity for female students to meet each other, as well as later-year students and lecturers. The event includes refreshments, campus tours, mentor and role model talks, and career talks. Feedback has been very positive with students sharing contact information for further interaction. The students from later years share their experiences and give advice to the first years on how to succeed, both in their studies and also from the social perspective, for example by joining clubs and societies. To date this event has been run successfully on all campuses. See Figure 1 (inclusive design of invite) and Figure 2 below.

Fig. 1. Inclusive design of invites

Fig. 2. Meet and Greet Coffee Morning

3.3 Scholarship Workshops

In recent years, industry is prioritising the recruitment of women into engineering and technology roles and are enabling this through financial investments in higher education scholarships. Academic scholarships, awards, and bursaries can have a significant financial impact on a student's life at university and can help with retention of women in engineering and technology programmes. In 2021, the TU Dublin Foundation had a total of €195,916 awarded to 85 students through 17 funds and scholarships, with a median award of €3,000 ("Scholarships". TU Dublin, 2023.). In response to this, WITU facilitated scholarship application workshops in October 2021. These workshops aimed to support female engineering and technology students in the scholarship application process. The workshops signposted students to available scholarships and helped students improve their applications through tips on completing forms, improving their CVs, and preparing personalised pitches.

Data was gathered from 16 Engineering and Technology scholarship application forms and requirements were summarised into an easy to digest toolkit for students. Some of the scholarships that the students applied for included; Huawei Tech4Her Scholarship, Huawei Seeds of the Future, Generation Google Scholarship, Marco Women in Engineering Scholarship and the Intel Scholarship for Women in Tech. The workshops were a great success with 46 students attending the workshops, 12 students applied for scholarships and 8 scholarships were awarded with a median value of €3,000 per scholarship. The workshops highlighted other initiatives for the female students to get involved in, such as, CodeFirst:Girls, TU Dublin Sustainability Hackathon, Dell Aspire mentoring programme and Workday Future Females in Tech events. These initiatives also help build the students confidence for scholarship applications for the following year and increase their self-efficacy in their ability to apply for these awards. The outcomes of these workshops are highlighted in Table. 2.

Table 2. Outcomes from WITU Scholarship workshops

School/Discipline	**Attendance at Workshop**	**Scholarship Applications**	**Scholarships awarded**
Business Technology	15	6	3
Engineering	16	1	-
Computer Science	10	3	3
Enterprise Computing & Digital Transformation	5	2	2

3.4 Industry and Alumni focused intervention: Annual IWD Networking Event

Students' perceptions of a career in engineering and technology can be based on narrow stereotypical views, which in computer science can sometimes be an image of a socially awkward, "geek" or "boffin" (Archer at al., 2013). According to Gladstone and Cimpian (2021) positive role models that have a perceived similarity and similar attainability of success to students in terms of their gender, race/ethnicity, age, and identification with STEM can positively shape a student's perception of careers in STEM. Students need strong role models and need to see successful exemplars who are just like them. As educators, we need to reinforce the slogan "if you can see it, you can be it" with our students.

In response to this, each year on the 8th March, WITU organises a series of university-wide, networking events to celebrate International Women's Day. These events focus on showcasing positive female role models in engineering and technology careers (both alumni in industry and university staff). In 2022, WITU members created videos for each school showcasing staff, alumni and students from their school speaking about their current career journeys and giving a one-liner piece of positive advice to female students in engineering and technology. These videos have been collated and disseminated on the WITU website. At these networking events, staff and alumni speak of the opportunities available to the students, from summer internships, third-year internship opportunities, industry-sponsored scholarships to international competitions and co-curricular activities that helped them on their career paths.

3.5 Coding4Girls - Attracting More Females onto STEM Programmes

The "Coding4Girls" is a funded one day camp which aims to inspire secondary school girls to explore the exciting world of technology and engineering. The objective is to encourage young girls to consider pursuing careers in technology and engineering and to promote gender diversity in the STEM field. Coding4Girls features a variety of hands-on activities and practical sessions, including fun coding challenges, programming arduinos to learn about robotics, and hands on design challenges such as tower building. Experienced faculty members lead these sessions and provide guidance and support throughout, enabling participants to learn in a fun and interactive way. Additionally, the participants have the chance to engage in informal chit-chats with current female students, allowing them to learn about the experiences of other women who have pursued similar interests and fields of study. The feedback from the camp was positive with 80% of the participants indicating that they would like to do more coding.

4 CONCLUSIONS

As well as the promotion of gender diversity within technology and engineering programmes across TU Dublin, these targeted events were a vehicle to expand the WITU network. A realisation is that even though female students may be the target audience, this does not mean that events cannot be opened to a wider audience. This is in recognition that all genders need to be part of the solution in achieving the aims of WITU and wider national aims around diversity and inclusion in STEM. A related conclusion is around the importance of language and imagery used in branding, invitations etc in terms of being inclusive.

Providing opportunities for the students to make friends and increase their network, particularly in year 1, increases their sense of belonging and community within the University. This in turn impacts their likelihood of success both academically and holistically. Feedback from students also highlighted the importance of lecturers knowing their name and the Meet and Greet Coffee events were an effective way to achieve this. Events where alumni are invited back to speak with the students, highlights the importance of role models who they can relate to in terms of similar attainment of success and in increasing attributes such as confidence, drive and self-efficacy. Similarly, by inviting scholarship recipients to speak at the workshops and give advice, the female students are seeing what success looks like and what they can achieve.

These targeted interventions are examples of how the WITU network supports and champions women in engineering and technology through collaborative practice in bringing together students, alumni, staff from across a wide range of disciplines within the University.

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REALISING A CENTRE FOR EDUCATIONAL DEVELOPMENT: EXPERIENCES, CHALLENGES, LESSONS LEARNT, AND FUTURE AMBITIONS

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ABSTRACT

In order to develop high-quality engineering education with a focus on students' learning, academic staff must themselves develop new skills, with a lifelong learning perspective to their own teaching. This requires coordination and support. For this purpose, three faculties at our university decided to jointly fund a *Centre for Science and Engineering Education Development*. Among the aims were to boost educational quality, strengthen educational competence among academic staff, and build educational quality culture on the institutional level. The faculties also recognized a need to establish a stronger and more focused didactic perspective for the university's programme STEM portfolio, beyond and in addition to the general pedagogical training already offered by the university. The centre's main responsibility has been to provide various forms of training of and teaching for academic staff and educational leaders, thus indirectly affecting also students' learning experiences. Strategic advice on educational change, dissemination of

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results, and strengthening of international and national collaborations, networks, and arenas, have been important additional tasks. This paper reflects upon the centre's activities, strategies, impact, experiences, and challenges from the start-up until today. We identify lessons learnt and propose advice for others planning similar centra. Among the topics covered are capacity and recruitment challenges, coping with diverse faculty cultures, and the need for a shared vision in which to anchor activities and resource usage. We will also describe a recent upscaling of the Centre’s mandate, responsibilities, and capacity, designed to support a major ongoing educational reform in the STEM programmes at our university.

1 BACKGROUND AND EARLY HISTORY

In 2016, three faculties at NTNU decided to jointly finance a *Centre for Science and Engineering Education Development* (acronym SEED). Education(al) development has been variously defined as “*helping colleges and universities function effectively as teaching and learning communities*” (Felten et al. 2017), actions “*aimed at enhancing teaching*” (Amundsen and Wilson 2012), and a “*key lever for ensuring institutional quality and supporting institutional change*” (Sorcinelli et al. 2005). The ambitions for SEED have, over its lifetime, included all these aspects.

The original initiative addressed a need for support of pedagogical development based on *Scholarship of Teaching and Learning* (SoTL) (Hutchings and Shulman 1999), both for the teaching-learning environments carrying out the educational work, and in support of educational strategies. It was decided that SEED should span the three faculties offering most of the engineering education, thereby including also departments for mathematics, computer science, and the natural sciences. SEED consisted initially of one person in a 50% position, with extensive experience and background from engineering educations. This person was given a nominal leadership of SEED, answering to a governing body of vice-deans of education.

The most important activities during the initial two years were to support educators and teaching-learning environments that asked for help, primarily with developing Learning Outcome Descriptions, both for courses, and for programmes. At the same time SEED established a network of contacts both on the national and international level, and in 2016 it facilitated the university’s joining in the *International CDIO Initiative*. The CDIO standards and syllabus subsequently came to provide an important conceptual framework for SEED’s activities (Crawley et al. 2014). Increasingly the university also came to be represented and active at arenas such as the Norwegian biennial conference for STEM education, a biennial Development Conference for Engineering Educations in Sweden, and the annual SEFI conferences. Furthermore, SEED provided advice on two successful applications for national *Centres for Excellent Education*, and contributed to development reports serving NTNU’s *Executive Committee for Engineering Education*.

It soon became clear that more manpower was needed to realise SEED’s potential and achieve the desired impact. When NTNU merged with three regional university colleges in 2016, an opportunity arose to engage co-workers, and in early 2017 SEED established a close collaboration with one of these colleges’ ongoing ‘Teaching Excellence’ projects. Two new employees with research and educational development expertise joined SEED. They contributed, among other things, with the following activities which were integrated into SEED's portfolio: Development and evaluation of interactive learning spaces, response technology in teaching and assessment, and the development of educational competence among academic staff through empirical peer guidance.

2 ACTIVITIES 2016 – 2022

A main contribution from SEED in its first seven years of existence has been to provide various forms of training of and teaching for employees, indirectly affecting also students' learning experiences. One particularly successful example of this, which became a key part of SEED's portfolio after 2017, is the *empirical peer guidance* for teaching faculty. The peer guidance programme was inspired by the REAP (Reassigning Assessment Practices) project (University of Strathclyde, n.d.) (Nicol and Draper 2009), as well as research literature which clearly demonstrates that with support, educators can transform research findings into new and effective practices (Thompson and William 2008). Educators were divided into teams and introduced to a theoretical framework that supported their understanding of their own teaching practice. Reflection and observations were important tools, as SEED guided an individual feedback process for the educators involved. The activity addressed both educator awareness and approaches to designing teaching-learning activities and assessment choices. The establishment of teams through peer guidance worked well, and several educators have made contact for further guidance and advice afterwards. Spin-off courses have also been run in the use of student response systems, advice on possible changes to formative assessment, use of electronic whiteboards, help with research on own practice, etc.

Furthermore, SEED focused on course and programme design, with particular emphasis on establishing relevant Learning Outcome Descriptions, designing appropriate teaching-learning activities, and addressing assessment formats. In fact, the most commonly asked-for support from academics has been about writing learning outcome descriptions, choosing and developing appropriate teaching-learning activities, and assessment. It is more than 10 years since the *European Qualifications Framework for lifelong learning* (EQF) (European Union, n.d.) was adopted in Norway. However, the use of learning outcome descriptions was rolled out nationally simply as a decree to be followed, without motivation, instruction or training, resulting in a widespread copy-paste (Sørskår 2015, Flobakk-Sitter and Fossum 2022) approach to writing learning outcome descriptions. A recent national evaluation of the national adoption of the EQF framework also indicates that it has had little impact on changing quality development work or extant teaching-learning and assessment practices (Flobakk-Sitter and Fossum 2022). Explaining, discussing, and improving the use of the national EQF framework, together with the idea of constructive alignment (Biggs and Tang 2011), has therefore been a mainstay of SEED's activity since its establishment. But while getting traction with the individuals who chose to attend SEED's workshops has been successful, establishing a *systemic change* in attitudes and support in the university routines still proved elusive. Few existing strategies were identified for systemic follow-up.

SEED's biggest impact in this phase may be the changes made in selected courses as a result of the centre's support on developing and updating teaching-learning activities, e.g., through the peer evaluation programme. However, SEED's support activities were also aligned with the establishment of parallel ongoing programmes and processes, both institutionally and nationally. Perhaps the most important example is that when a national programme for recognizing *Centres for Excellent Education* (CREs) was established, the university responded by establishing corresponding incentives and development projects both on the university-wide and on the faculty level. These local activities aimed to support the development of environments that could grow to become future national CREs. SEED has been an active advisor on many CRE proposals, as well as on grant proposals from other relevant national and international funding institutions. Two CREs have so far been granted to NTNU. A second important example was the national initiative on *establishing systems for recognition of pedagogical merits*, partly in line with the conceptual framework developed by *The Career Framework for University Teaching* (Career Framework for Teaching 2022), but also based on experiences with such merit systems from neighbouring countries. Here, it was helpful that one of SEED's team members was centrally placed in the establishment of merit systems on the national level. Today NTNU has recognized close to 40 *excellent teaching practitioners* according to this system, with SEED having given important guidance both on the institutional and individual level during the development phase.

The development of interactive *learning spaces* has been another ongoing initiative from NTNUs leadership and property division. SEED has been an active and close collaborator throughout its existence, starting with advice on the design of such spaces. SEED has provided training and support to educators who want to change their teaching practice, by introducing a more active learning approach and using spaces that are designed for this purpose. At the same time, we have conducted several evaluations of the impact of such spaces built on experiences of both students and educators. Our insights from these evaluations have led to participation in several development projects concerning learning spaces at the university, in particular under the umbrella of NTNU's long-term campus development project.

Another important focus has been on establishing NTNU in national, European, and international networks for engineering education research and development. Significant time and effort was spent on informing about SoTL at large, and about the CDIO framework in particular. SEED has thus been instrumental in supporting a growing interest in engineering education research, providing support both in identifying research questions, choosing methodologies, and disseminating results, nationally as well as internationally. NTNU's presence and impact in international networks has profited from SEED's activities and international engagement. As mentioned earlier SEED was the driving force for engaging with the CDIO network, and has had considerable impact on NTNU's increased SEFI participation.

3 CHALLENGES 2016 - 2022

The challenges SEED experienced during the period 2016-2022 may be of general interest. We will first describe the education portfolio challenges identified by SEED, and subsequently challenges experienced by the centre itself regarding its work capacity, operational efficiency, and overall impact.

After a while it became clear that the conditions for quality development of the university's STEM education programmes were lackluster in several aspects: A general lack of knowledge about the design and development of teaching and learning practices in line with progress made over the last quarter century in university pedagogics and didactics; a systemic lack of dialogue between departments providing courses and programme managers with responsibility for programme development; and a lack of awareness of how administrative routines should be designed to support rather than hinder educational development.

While this may seem very critical, it should not be taken to mean that the attained learning outcomes of the graduates was in a bad state. Decades of adapting to existing conventions of primarily lecture-driven teaching with written final exams, excellent student recruitment, and a culture supporting engineering projects, made up for most of the shortcomings. The graduates have been highly competent, as witnessed by their strong popularity and reputation in industry and society at large.

The major challenge was, and remains, to transform the educational design of the university into *agile processes that can be continually developed and improved upon*. The established system has evolved to update the scientific and technical contents of the educational programmes in a proper way. However, it faces considerable challenges if the graduates are to develop a broader set of professional competences that includes creativity, communication, collaboration, reflection, and negotiation skills covering both digital transformation and sustainability, providing the basis for competence profiles needed to face the 21st century's challenges.

The challenges related to the establishment, development, and impact of *SEED itself* have mainly been related to the governance model, challenges pertaining to long-term commitment of faculty resources, diversity of faculty cultures, capacity reduction due to people leaving, and the lack of an overarching vision for the science and engineering education at our university. The latter challenge could in fact be seen as a root cause of many of the other challenges. SEED's original incarnation provided support for development of educators, courses and sometimes study programmes, and the centre personnel provided valuable advice on both strategy, systemic development, peer coaching, learning spaces, and infrastructure. However, without a clear governance model based on a shared strategic vision, the very freedom awarded to SEED meant that internal prioritization between these activities was hard to do. Many possible activities in practice competed with each other on equal terms, without the clear priorization that could have resulted from a more clearly formulated vision on which to base governance. The diversity in faculty cultures and varying attitudes to changes in pedagogical approaches (or even the need for change) also affected how different teaching environments responded to offers of support from SEED. Such offers were sometimes interpreted as just extra work in an already busy work schedule. This situation was to undergo a significant change with the university-level development project *Technology Education of the Future*, which provided both a vision, an updated conceptual framework, and an ambition level that created a concrete need to develop an up-scaled 'SEED 2.0'.

4 THE ‘TECHNOLOGY EDUCATION OF THE FUTURE’ REFORM: A FRAMEWORK FOR FUTURE ACTIVITIES

The recent upscaling of SEED’s mandate, responsibilities, and capacity is designed to support NTNU’s ongoing educational reform of its engineering, technology, and science programme portfolio. Through an institutional development project, “Technology Education of the Future” 2019 - 2022, a holistic conceptual framework was developed for re-design of the NTNU’s educational programme portfolio in technology and engineering. This project delivered its final report in January 2022 – a roadmap focusing on the concrete steps NTNU should take in order to implement the project’s developed vision. The roadmap outlined 12 Main Actions (MAs) within five quality areas, plus an overarching ‘umbrella action’ to enable the MAs. For each MA, *Prioritised Measures* (PMs) were described (Øien and Bodsberg 2022).

One of the recommended MAs was to *‘Facilitate and support educational competence development’*, and one of the central PMs proposed under this MA was to *strengthen the university’s existing Centre of Science and Engineering Education Development*. The idea was to further strengthen SEED’s capacity for educational competence development and project implementation support, and to develop and establish the centre as a hub able to join together didactic resources and other support functions from different sections of the university, both local and common. A strengthened and long-term funded SEED could support the project implementation on everything from study programme design and learning outcome descriptions to pedagogical support for individual educators, and act as an operational “right hand” for the university’s *executive management committees for engineering and technology studies* in their work on further quality development. Furthermore, SEED could provide practical and strategic support for faculty leadership and department heads in the project implementation process.

While these tasks were present already in the original ambitions for SEED, the ‘Technology Education of the Future’ framework implies significantly raised ambitions, complexity, and scope, plus a clear strategic direction and a raised bar for strategic commitment from the university. Four faculties participating in the ‘Technology Education of the Future’ project therefore decided to co-fund a doubling of SEED’s man-year capacity from 2023. The centre now consists of a Director (60 %), an Educational Development Expert (100 %, two Educational Developers (50 % + 20 %), and a Coordinator and Advisor (50 %).

The upscaled SEED’s activities are currently under planning and will commence in earnest from Fall 2023. The Spring Semester 2023 has been mainly used for

- ensuring continuity in activities that were already ongoing and/or committed to before the recent upscaling of SEED,
- developing an overarching vision: ‘*SEED shall be a central, highly competent, and active contributor to the development of the university's study programme portfolio within technology, science, and economic-administrative subjects, towards internationally outstanding educational quality and reputation*’,
- developing clear criteria for prioritization between potentially competing activities, based on the needs for support and development that are seen to be the most

- important or urgent from the funding faculties' side, and tentative long- and short-term aims formulated for SEED's future activities,
- aligning and coordinating SEED's efforts with those of other learning support and educational competence development functions at NTNU,
- identifying specific resource persons and educational experts who may be recruited to SEED in part-time positions,

We have identified a need to support STEM-specific didactical competence development for both newly appointed and experienced subject educators. It is particularly important to develop competence in facilitating comprehensive competences in STEM subjects, and to show how a programme-driven approach to curriculum development, teaching, and assessment can be implemented in practice. This will complement and deepen the university's general programme of basic educational competence for all newly recruited faculty provided today. We have also concluded that all university staff involved in education will need some kind of further education supporting *STEM-specific educational competence development*. SEED can contribute here as well, by offering competence development modules in specific areas such as, e.g., the integration of sustainability competence in curricula, an increased degree of calculation-orientated mathematics, strengthening innovation competence, and appropriate forms of assessment and teaching. Key SEED personnel also have a high expertise in developing, assessing, and recognizing pedagogical merits, and can contribute with support for development and documentation of such merits for academic staff.

Summarizing the above points, we have identified the following themes as particularly important to prioritize going forward:

- Support for study programme (re-)design according to the design principles advocated by the *Technology Education of the Future* project, starting from the project's established graduate competence profiles
- Interpretation of and implementation advice on results and recommendations from the project at large
- Offering didactic competence development modules and courses, on specific topics such as, e.g., active learning and constructive alignment, tailored to a range of specific target groups. These include PhD students, newly hired faculty, study programme managers, course responsibles, and, importantly, educational leaders on the department and faculty level.

Furthermore, we see it as vitally important to support an *increased discoursive pressure* about education. By this we mean strengthening and firmly establishing the ongoing dialogue among all university staff about all aspects of education - its outcome, contents, and design. This includes facilitating new arenas and fora which strengthen the university discourse on education development, motivating faculty to participate actively in relevant international and national networks for educational development, providing advice on innovative assessment practices, and on proposals for funding of educational development projects.

A central precondition for all of the above to work is that SEED communicates its services and competence proactively and professionally to the target groups, and stays visible and in demand on all levels from the local to the international. A strategic communication plan is being developed to support this aim.

5 CONCLUSIONS AND LESSONS LEARNT

This paper has described and reflected upon the strategies, impact, experiences, and challenges of NTNU's Centre of Science and Engineering Education Development (SEED) from its start-up until today. We have identified lessons learnt and proposed advice for others considering to establish similar centra. Among the topics covered have been capacity and recruitment challenges, coping with diversity in faculty cultures, and the need for a shared vision.

From 2023, the "Technology Education of the Future" project provides SEED with an shared overarching vision and a common framework for all participating faculties. The project implementation has also been enshrined among the explicit aims for the university in its development agreement with the funding ministry, making it an institutional priority. This has already had positive effects in terms of capacity, visibility, and impact. Important and positive as this capacity increase is, it must be emphasized that it is still crucially important that all the university's educators understand and acknowledge that they are also part of the change and development. A centre like SEED cannot just come in and "eliminate the problems" - if sustainable and lasting change is going to happen, the educators and educational leaders must themselves take ownership and have an active role in developing a quality culture.

Based on our experiences and reflections we conclude that if a centre such as SEED is to have the desired impact, the following factors are particularly pertinent:

- The faculties involved need to have a common understanding and vision, from the leadership on down, of what their engineering programme portfolio and closely related education programmes should achieve, and what the centre's mandate and responsibilities are towards this achievement.
- The centre needs to be closely aligned and in continuous dialogue with the pedagogical development strategies of the governing faculties.
- Based on these two conditions, the centre must strategically plan and prioritize its resources, and develop its own capacity and competence, to provide strategic advice and solid support for education-related competence development among all staff categories involved in education activities. All the while it needs to communicate actively to make itself visible, relevant, and in demand.
- The university needs to develop its systemic and administrative routines to actively support educational quality development, and the centre needs to provide advice in this work. This is in line with (Havnes and Stensaker 2015): '*the educational development centre is on its way to be transformed from a merely technical activity focusing on how individuals become good teachers, into having a broader focus in which the organisation, frameworks and infrastructure surrounding the teaching and learning experience is addressed.*'

A number of challenges are still involved in achieving the above, which SEED is working systematically on. This includes, e.g., how support on the various prioritized themes should be designed, and which demands the various activities will have on SEED's resource and staffing needs. The last bullet point above may be challenging both with respect to identifying the most relevant routines, and with respect to unintended collateral changes which may occur should the routines be changed. Changes are also complicated by legal aspects and financial constraints.

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"Keep It Simple: Optimized Course Evaluations with Moodle"
A test run for user-friendly Moodle-based course evaluations

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Conference Key Areas: *Virtual and Remote Education in a post-Covid world, Curriculum Development*
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ABSTRACT

Acquiring representative feedback from students is a common problem for universities. To address the often low response rates and participation bias, we focussed on a simplified evaluation process and improved user convenience. We developed and implemented a new tool for collecting feedback by sharing an accessible short survey on our Moodle-based e-learning platform. This new Moodle evaluation tool allows surveys to pop up visibly but non-invasively within every Moodle course offered by our university for the duration of the valuation period. After voting, the survey does not show up again. By condensing a questionnaire to three main queries using a 6-point Likert scale, we gathered data on overall satisfaction with the course, satisfaction with course structure and navigation, and satisfaction with course elements and content. Within two weeks, we collected 65,000 votes from over 1600 courses, with an average response rate of 30% among all active students using the Moodle platform. This paper describes the design and implementation of the short survey, provides an overview of the new evaluation tool and its features, and shares preliminary results and interpretations of the data. Based on these findings, we outline our plans for the continuation and extension of the short-survey approach.

1 INTRODUCTION

Collecting student feedback is a crucial element for maintaining and improving the quality of educational courses at universities. The insights gained from student perspectives can help instructors identify areas in need of improvement, adjust course materials, and enhance overall teaching methods. Despite its importance, acquiring representative feedback from students often remains a challenge due to low participation rates. Here, we address this issue by presenting a remodelled tool for collecting student feedback within Moodle.

The shift from in-class pen-and-paper surveys to digital surveys over the past decades has often led to decreased participation rates (Dommeyer et al. 2004; Asare and Daniel 2018; Casey and Poropat 2014; Plante et al. 2022). Contributing factors include a decreased sense of immediacy, personal connection, and social pressure in digital environments (Fan and Yan 2010). Digital surveys are more easily ignored or postponed than paper-based surveys used to be in the classroom setting. Also, digital surveys often require students to follow external links and therefore aren’t well integrated into the learning experience (user-flow) of the students (Dommeyer et al. 2004). These technical barriers also exist within our current institutional evaluation system, the commercial EvaSys platform. That is why we substantially re-designed and beta-tested the Moodle evaluation plug-in *Course Feedback*, with a focus on a convenient, non-invasive user-experience that reduces disruptions and promotes student engagement in the evaluation process.

The Moodle plug-in *Course Feedback* integrates an institution-wide survey directly into the online course environment of the Moodle-based e-learning platform used by the university. The aim is to reduce the time and effort required to complete the survey and make this process as seamless as possible. By integrating the survey on top of each course page, students can provide feedback without having to navigate away from their course materials.

In the following we describe the design of *Course Feedback,* its new features, and its implementation and test in a university-wide short survey. We also present preliminary results and an interpretation of the data collected. Finally, based on these findings, we will outline our plans for the continuation and extension of use cases for *Course Feedback* and the short-survey approach to further enhance the effectiveness of course evaluations.

2 METHODOLOGY

2.1 Design and integration of a user-friendly Moodle evaluation plug-in

The re-design of the Moodle plug-in *Course Feedback* was aimed at improving the user-experience for online-evaluations through a seamless integration into the Moodle course environment. Students should not be disrupted in their workflows, while the survey still has to be clearly visible. Instead of using links to an external evaluation system, the survey now appears as a notification banner at the top of every Moodle course for a defined time period (in our case: two weeks). It is fully embedded into the course page and appears directly under the course title (see Figure 1). The participation is voluntary and users can opt to simply ignore it, scroll down, and directly start using the course page. Nevertheless, the survey remains at the top of the page until the user completes the voting process, the course administrator deactivates it or the end of the evaluation period is reached. Users also have the option to skip participation in the survey by closing the evaluation window with one click. However, this does not deactivate the banner. The banner will reappear when the student logs in to the course page again.
To prevent lengthy text blocks accompanied by multiple choice boxes as well as to add some playfulness and increase visibility, we chose a tile-based design featuring text and descriptive emojis. To participate, users click directly on one of the six emojis of the first question. The response is registered immediately, the banner fades out, and the next question fades in. After the final question, the entire survey vanishes automatically, and students find themselves again at the top of the Moodle course they initially chose to work in when logging in. Due to this minimalistic design, users can respond to (in our case) three survey questions with just three clicks. Neither initiating nor concluding the feedback process requires any further actions. Everything happens within the course page.

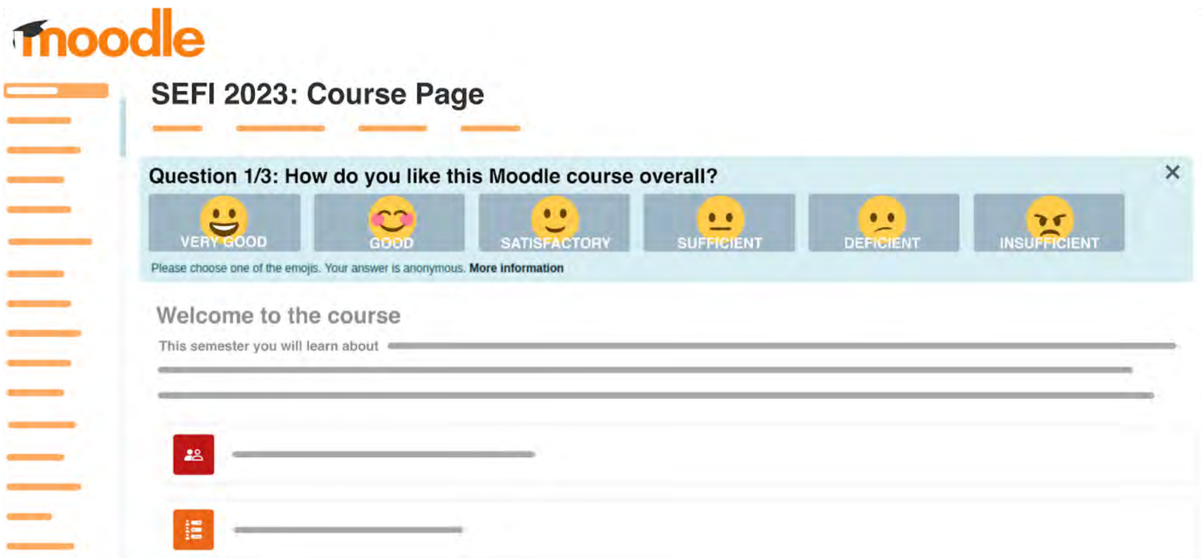

Fig. 1. Course Feedback *integrated into a Moodle course environment as it appears during the active period in every course until the survey is completed.*

2.2 Data collection

The data generated by the survey is anonymous, it does not collect user identification information. At the same time, the information on the notification banner is different for participants and trainers. While participants are asked to give feedback once in every course they are enrolled in, course trainers have access to the real-time results and an option to disable the survey in their own courses.

3 RESULTS

3.1 The Short Survey and Summary of Findings

Following the expectation that shorter surveys reduce survey fatigue and thus improve participation rates (Asare and Daniel 2018), we adopted a minimalist approach for this survey, consisting of only three short questions:

1. How do you like this Moodle course overall?
2. How do you like the navigation within this Moodle course?
3. How do you like the digital activities and materials available in this Moodle course?

The responses were measured on a 6-point Likert scale (0=insufficient to 5=very good). We conducted the two-week survey in the last weeks of the lecture period. At that time 50,113 users were enrolled on the Moodle platform. Of these, only 16,433 logged into Moodle (and would hence see our survey). We considered these as “active users”. Students were asked to give feedback in every single course they actively visited during the survey time period. The total number of responses for the first question was 22,724, while the last question still had 21,041 responses, showing a very low dropout rate of survey participants. Over 92% of students who started the survey also finished it.

This high completion rate can be attributed to the short, user-friendly design of the survey, which required minimal time and effort from participants. We achieved this by keeping the survey concise and by implementing a user flow where follow-up questions appeared directly after a response was provided, instead of students having to scroll through a survey form. The low dropout rate underscores the effectiveness of the short survey approach.

An analysis of the response rates over the entire 14-day period revealed that nearly half of the responses were collected within the first two days (Wednesday and Thursday). This indicates that a large proportion of participants clicked through the questionnaire immediately when being first confronted with it.

At the time of the survey a total of 19,590 courses were hosted on the platform out of which 2,200 courses were active (at least one user log-in during the period of the survey) in the two-week period of the survey. Out of the active courses, we received at least one response in 1,636 courses, with a total average response rate of 30%. For further analysis, filters were implemented to exclude courses with low numbers of responses and low participation rates. That way we were able to exclude courses with very low activity and also non-teaching related courses such as test courses, templates, organizational courses, etc. Consequently, we only incorporated courses with a minimum of five responses and a response rate (among active student users) of at least 20% into our analysis. This resulted in a selection of 783 courses for in-depth data analysis. By excluding the courses with low activity, the response rate within the subset increased to 37.2%.

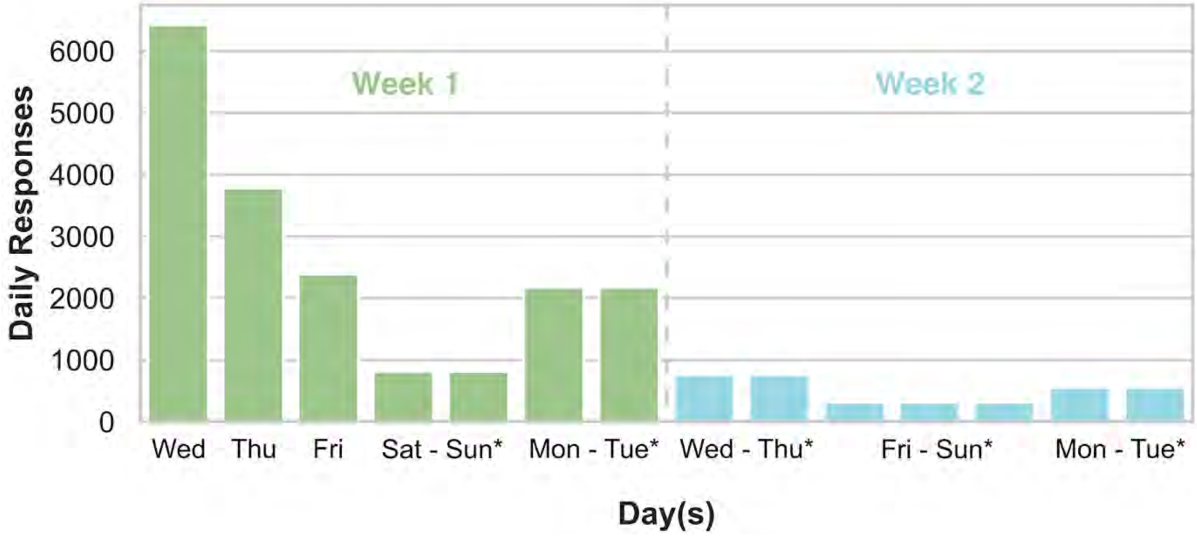

*Fig. 2: Responses per day across the 14-day run time (*averaged from two to three day spans, as after the start-phase data was acquired irregularly)*

3.2 Preliminary Analysis of Survey Responses

Even though the primary focus of this article is to describe the re-design of the *Course Feedback* Moodle plug-in, we also want to briefly discuss data collected in the survey and what we learned for future implementations of such surveys.
To facilitate a comparison of course ratings, and to avoid comparing (for example) very large and less personal lectures with intimate seminars, we sorted courses into four distinct size categories:

- Small (0-20 active students)
- Medium (21-50 active students)
- Large (51-120 active students)
- Massive (over 120 active students)

The analysis revealed that smaller courses tend to receive significantly higher approval ratings across all three evaluated questions (see *Fig. 3*).
Factors that contribute to the higher approval ratings for smaller courses likely include the more personalized learning experience they offer, as well as the increased opportunities for direct contact with instructors. Additionally, larger courses often fall under the category of mandatory courses, which might be generally less popular compared to elective courses. However, we are aware that the comparability of courses across disciplines and course formats, even within these size categories, is difficult and feedback might vary widely (Stark and Freishtat 2014).

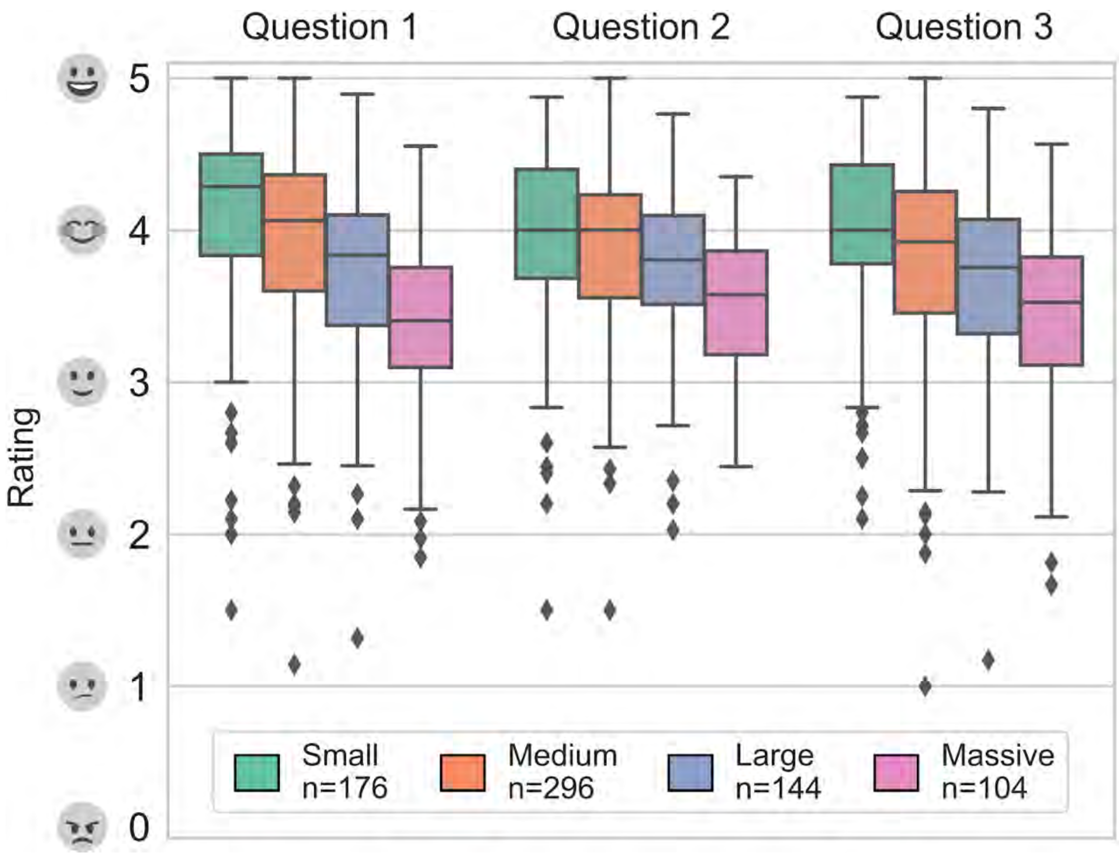

Fig. 3: Question 1-3: Average course ratings sorted by course size

3.3 Limitations of the Study

While the short survey showed promise, its limitations must be recognized. One concern is whether it measured satisfaction solely with the Moodle course design or the entire course experience. The survey focused on satisfaction with the Moodle course's structure, navigation, and content, but students may have included feedback on the overall course experience, including in-person components.

Another limitation is that the short survey may miss some important aspects of the course experience and thus not always provide a comprehensive understanding of students' experiences.

However, the trade-off between data quality and increased participation rates should be considered when evaluating the overall effectiveness of the short survey approach. Note that our technical implementation is not limited to short surveys.

3.4 Future Research

This was the first step of a larger research project. Several directions for future research will be explored to further use the *Course Feedback* plug-in and to further analyze the data acquired.

1. Analysis of the top-ranked courses of each category to identify impactful course design elements.

2. An additional analysis of a dataset of all the course activities (e.g. assignments, quizzes, videos, group organization, etc.) to gain insights on the user satisfaction with different course design approaches.
3. Improved survey questions and open text field option, including course-specific questions added by trainers.
4. Broader application of the *Course Feedback* tool: our tool offers to the University to efficiently gather student feedback within Moodle and make data-driven improvements. For example, our university Moodle system was recently updated from Moodle V.3.11 to V.4.1. A survey about the overall satisfaction rates between the two versions could be easily undertaken now.

4 SUMMARY

In conclusion, the *Course Feedback* tool has proven to be an effective and user-friendly solution for collecting student feedback in Moodle courses. By seamlessly integrating the short survey directly into the course environment, the tool minimizes barriers that often deter students from participating in evaluations, such as time constraints and disruption to their learning experience. While the short survey approach may have certain limitations in terms of data comprehensiveness, the overall success of the *Course Feedback* tool in improving the user flow showcases its potential for broader applications.

The technical implementation and the minimalist design, featuring only three concise questions, streamline the feedback process and could encourage higher response rates. Furthermore, the low dropout rate indicates that students found the tool easy to use and were inclined to complete the survey once they began.

Future enhancements to the tool could involve refining survey questions, incorporating open text field options, and expanding its use across different platforms and educational contexts.

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INNOVATIVE ENGINEERING EDUCATION IN THE WAKE OF SMART AGRICULTURE. REVISION OF THE AGRICULTURAL ENGINEERING CURRICULUM

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***Keywords**: Agricultural Engineering (AgEng), Lifelong Learning (LLL), Cross-Competences, Education, Smart Agriculture (SA)*

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ABSTRACT

Global developments request ever more productive agricultural production systems to ensure food security. Agricultural production must be environmentally, socially sustainable and economically efficient. Innovative digital technologies are central to sustainable production systems. This poses challenges to the education of agricultural engineers, as technologies for real world challenges result from highly interdisciplinary innovations.

Agricultural engineering (AgEng) as academic discipline is not universally established, which leaves voids in educational curricula and formal training areas. A substantial conflictual dualism remains between the biological and engineering domains. There are currently no homogeneous pathways through which these domains merge on common scientific and cultural foundations, cumulating in consistent training areas. The diffuse institutional situation damages the position of AgEng as an academic discipline. The ambiguity of AgEng has become evident during the evolution of Smart Agriculture (SA), where digital technologies deeply interact with conventional agricultural technologies.

In the course of rapidly spreading SA technologies, the present paper formulates a rigorous approach to defining competence formation in AgEng to integrate cross-competences, which can be offered through lifelong learning (LLL) opportunities.

1 INTRODUCTION

Global demographic developments, climate change and political crisis call for more efficient agricultural production systems in order to ensure food security on global level. At the same time, contemporary agricultural production cannot simply intensify, but must produce environmentally, economically and socially sustainable (European Commission 2023). This poses clear targets and challenges to the education of agricultural engineers, as the solutions to such real world problems are characterized by highly interdisciplinary challenges and innovations.

Digital technologies of the socalled Smart Agriculture (SA) are central to address the challenges posed to agriculture (FAO 2022). Remote sensing, geo-localization, automated harvesting, monitoring and precision pest management are only a few technologies proposed under the term SA (VDI 2021). The present article looks into educational aspects and competence formation that this development has on the discipline of AgEng.

1.1 Agricultural Engineering: Definition and status

Conceptually, AgEng's primary goal is providing technological solutions to sustainable biological production systems (Holden et al. 2020). Aggregated goals are the preservation of nature, environment and landscapes. Central capacities of AgEng are the development of agricultural machines, technologies and production systems, thus, the technological soul of agriculture (Lazzari and Mazzetto 2016).

For the European Society of Agricultural Engineers, EurAgEng, "Agricultural engineering combines the disciplines of mechanical, civil, electrical and chemical engineering principles with a knowledge of agricultural principles according to technological principles. A key goal of this discipline is to improve the efficacy and sustainability of agricultural practices" (EurAgEng 2023). Comparable conceptualizations are drawn in non-European contexts, as in India (Singh 2015) or the USA (ASABE 2023).

The tools and skills to achieve these goals are partially provided by other engineering disciplines. Engineering and agriculture are highly dynamic professional and scientific sectors, especially since the emergence of digital technologies and processes. On academic level, many of the innovative research topics have a strong interdisciplinary character. In this context, scientific fields tend to expand their scope, creating competing skills and overlapping roles.

In consequence, the sphere of action of the agricultural engineer is compressed by the expertise of other fields of engineering, which tend to be better defined and structured, often moving discussions to focus on specific aspects of a problem. This, however, leads to a shortage of far-reaching visions.

Thus, while the mission of AgEng as a discipline is clear, its practical educational implementation is confuse. As a result, AgEng as a discipline lacks coherent development. Digitization poses further challenges to AgEng as it requires the re-ordering and potential enlargement and further collaboration with other disciplines.

The CIGR, the International Commission of Agricultural and Biosystems Engineering, maintains an open definition, promoting "sustainable biological production systems while protecting nature and environment and managing landscape through the advancement of engineering and allied sciences" (CGIR 2023). However, the adjective 'agricultural', to describe a core task, fell out of use. Fig.1 below displays the current seven CIGR subjections that cover the field of agricultural and biosystems engineering (CGIR 2023).

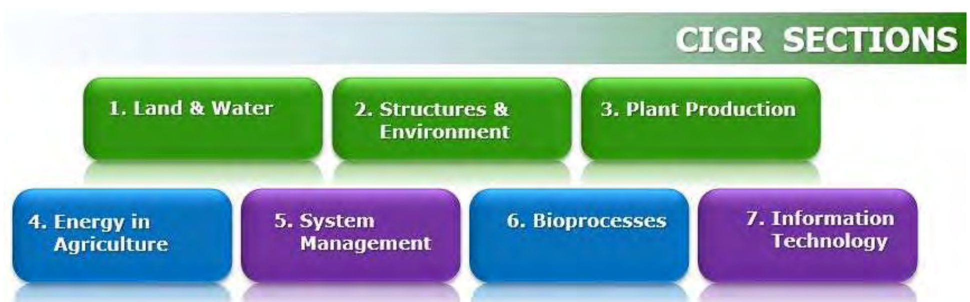

Fig. 1 The seven sections of the International Commission of Agricultural and Biosystems Engineering, CIGR

A comparable structure is pursued by the Italian Association of Agricultural Engineering, AIIA, which maintains seven sub-sections (AIIA 2023). Despite the tutelage by various associations, AgEng, as scientific subject and professional qualification, lacks representativeness and visibility in research and education institutions. There is a clear risk of thematical overstreching and conceptual blurring.

This is demonstrated by the plain absence of specific items relating to AgEng in the vast list of the European Research Council, ERC, categories. The term engineering is widely present, however not in combination with agriculture (ERC 2023). The adjective 'agricultural' is apparently problematic, as it doesn't focus anymore on a specific domain of interest (DomInt), i.e. cultivated lands or animal husbandry. It rather addresses a too wide concept of 'biological production systems'. DomInt's intend portions of the real world over which we have knowledge or interests, driven by application purposes. Today, educational and academic institutions have difficulties to relate to AgEng DomInts as these are often crossing through various scientific and cultural foundations (Singh 2015).

2 METHODOLOGY

The diffuse position of AgEng in academia and institutions risks further deterioration inflicted by emerging SA technologies, which are brought forward by diverse engineering branches and information technologies. This practice paper seeks to conceptually develop educational units and curricula around AgEng, building on cross-competences and transversal capacities, in order to develop a conceptual model of rigorous competence formation in AgEng.

2.1 Conceptualization and competences of AgEng

To structure the position of AgEng in science, we may consider the correlated Scientific Disciplinary Sectors (SDS) with inherent DomInt's. Central DomInt's for AgEng are agriculture, engineering, biology, informatics and others. The DomInt determines a portion of the real world over which we have knowledge or control interests driven by application purposes. The DomInt of AgEng focalizes on production systems with environmental and biological elements that are difficult to control. Obviously, AgEng concerns several DomInts, as productive biosystems, mechanical engineering or digital technologies. DomInts, their areas and topics, are part of specific SDS, which are conceptual spaces that contain also investigation methodologies and objectives. Combining these elements, SDS represent recurring investigative approaches of enquiry, analysis and study, driven by specific application purposes and with modes of representation and documentation characterized by its own terminology. In Italy, where the scope of university education is structured in cognitive areas, for instance medicine, engineering, agricultural sciences, economics, these areas channeled in distinct SDS. The competences and cross-competences, expertise and skills of AgEng are actually divided into three distinct SDS, relating to the application fields of a) hydraulics and hydrology, b) machinery and plants and c) rural constructions, territory and landscape.

Inside a given DomInt there is thus a synthesis of several cognitive activities, deriving from a variety of expertises of various professional fields that characterize through an interdisciplinary approach the aspects of interest of the real system. The concept of "macrodomain of prevailing interest" (MD) considers the general and prevailing standpoint by which an analysis on the same real world is carried out. In each macrodomain, the related standpoint determines the purpose of the analysis with corresponding methodological approaches. The example of maize cultivation (Fig.2) indicates the many different standpoints by which the enterprise can be analyzed.

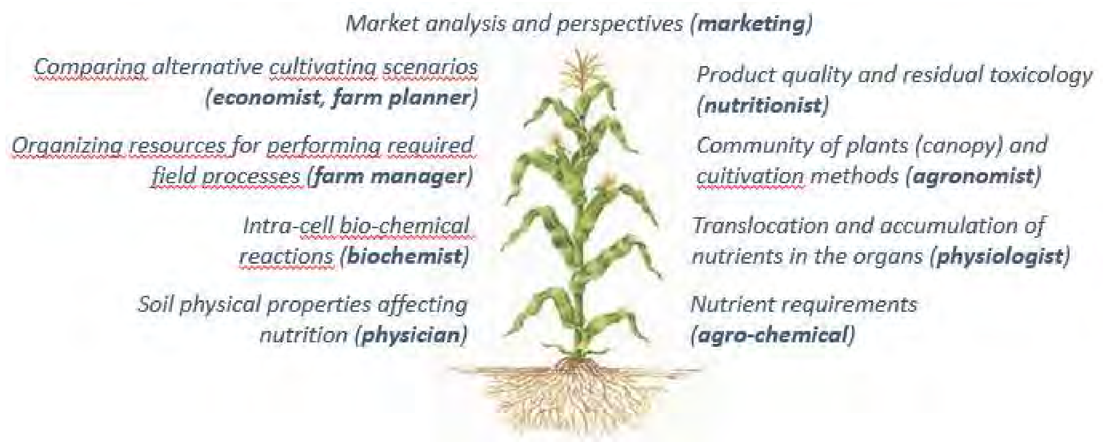

Fig. 2 Example of maize colitivation with respect to possible macrodomains of prevailing interests (MD)

The example in Fig.2 shows, how in respect to the specific interests, MD's differ. If prevailing interests concern e.g. nutrient requirements, the physical and chemical MD will prevail over others. Accordingly, for analysing the organization of field processes, social and organizational MDs will dominate. This doesn't mean that other MD's are neglected, as they scrutinize the complete system. MD's shift their emphasis according to prevalent interests.

MD's relate to decision-making by identifying one predominant viewpoint through which a system can be analyzed according to prevailing purposes. With regard to AgEng, four main MDs are significant (Fig.3).

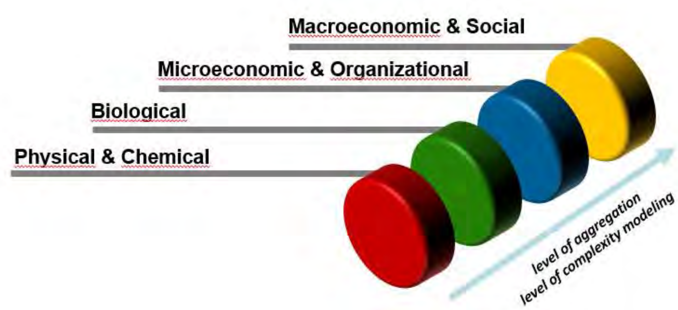

Fig. 3 Four macrodomains of prevailing interests (MD) relevant in AgEng

The outlined four MD's are the prevailing persperctives on relevant tasks in AgEng. Such methodological foundations are useful to clarify educational challenges, for instance with reagard to mountain agriculture. To form competent agricultural engineers, university courses must offer educational paths that create new knowledge around a given DomInt. Universities grant and promote the formation of autonomous sets of skills and cross-competencies supported by different levels of experience (internships, mentoring, collaboration with enterprise networks). The higher the interdisciplinary profile of the DomInt, the more robust the training in cross-competence topics, the more AgEng university courses offer real world capacities.

Structurally, AgEng courses are firstly articulated on teachings focused on sector-related expertise, while ensuring a proper level of cross-experience topics. Fig.4 displays the different thematic weighting of various MDs in university courses or programs.

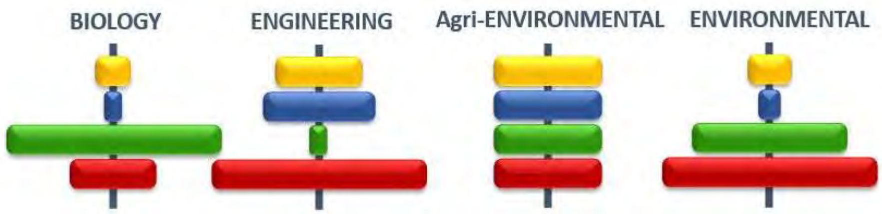

Fig. 4 The design of courses and programmes according to macrodomains of prevailing interests

Fig.4 outlines very well, how in highly specialized courses a given MD tends to dominate over the others. In the case of an engineering course, the physical and chemical MD is predominant. In the past, some highly specialized bachelor programs were held in Italy, which eventually had little success. A lack of professionalism and falling interest was the result. AgEng courses should always ensure an equilibrated profile, avoiding over-specialization, as an universalist approach relates better to everyday tasks in agriculture.

Bringing this logic into university programs, the schematic overview of bachelor (left) and master courses (right) looks as displayed in Fig.5 below.

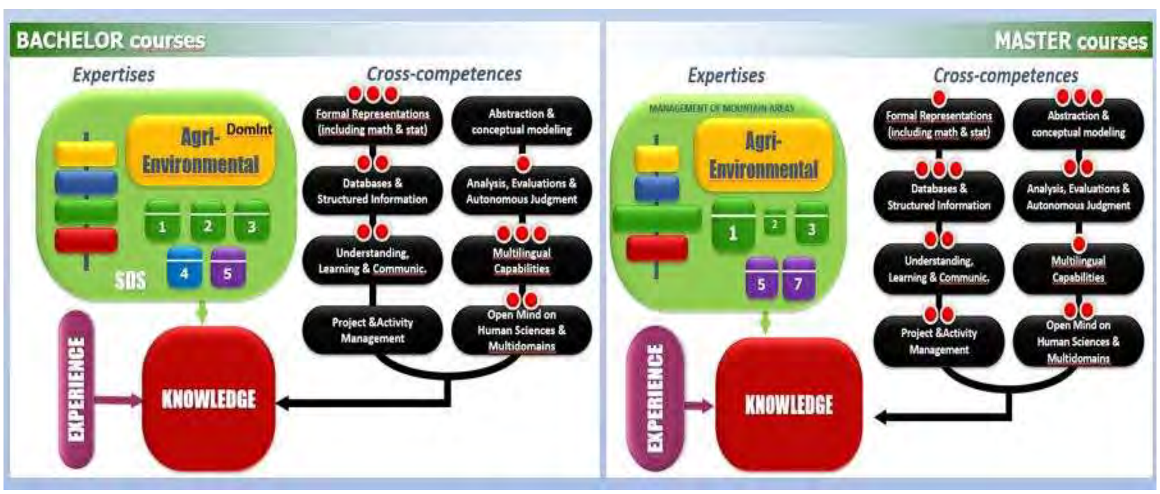

Fig. 5 Schematic juxtapositon of AgEng Bachelor's and Master's degree programmes with different thematic focuses. Red dots indicate relative importance.

Structurally, the left and right scheme of bachelor and master courses are equal, but weightening the various elements results differently. The four blocs in each scheme are related to each other: Expertises, cross-competences and experience generate, as final target, knowledge. Expertises consist of the agri-environmental DomInt (topics, methodologies, objectives) with orientation from five CIGR sectors and balanced MD's. This bloc (SDS) is juxtaposed to cross-competences of various weight (red dots). Experience is gained through autonomous activities as working placements, stages, mentoring programs or professional collaborations.

The bachelor's degree is build around balanced MD's and the CIGR sections 1 to 5. Additionally it introduces a first selection of cross-competences. This set up leads towards holistic and rigorous competence formation in AgEng. It describes the basic level of AgEng competence, but represents and underlines the broad picture of tasks within the discipline.

The master course with agri-environmental focus addresses specific tasks and developments as different MD's indicate. There is a focus on CIGR topic one to advance students' specialization on natural resources. This corresponds with a nuanced weighting of cross-competences towards abstract thinking and independent reasoning.

2.2 Smart agriculture: Curricula integration and cross-competences

The need for new educational elements in AgEng has become particularly evident with the appearance of SA, where digital technologies deeply interact with the traditional technologies of the agricultural sector, even with significant impacts in many application domains (crops, orchards, animal, soil, water, soil etc.) and related major impacts on the quality of management at farm level.

SA solutions enhance the management quality of decision making processes in agriculture as they allow to make decisions based on targeted information previously collected through monitoring procedures (Mazzetto, Riedl, and Sacco 2016). This

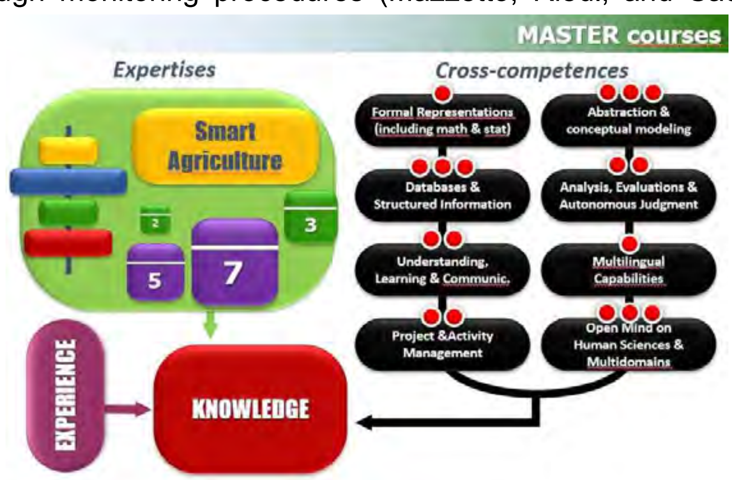

Fig. 6 Combination of skills and cross-competences in SA in the framework of a master program

adds complexity to the curricula and training of AgEng professionals, especially in context of an ever proceeding digitization and automatization of the agricultural technology chain. Digital skills can be integrated into existing AgEng education through both, expertises (DomInt's, MD's) and cross-competences. Following the previous structure Fig.6 provides an overview on the setting of a master course around SA technologies, including differing MD's, DomInt's, CIGR sections and cross-competences. Cross-competences take an even bigger share in the SA master program as there is a need for flexibility and stabilized transversal skills. The focus lies on the management and organisational MD, as well as on the 7th CIGR panel, information technologies. While the Agri-Environmental master requires many cross-competences, the drafted master in SA poses even more weight on cross-competences.

A promising option to include innovative cross-competences into the AgEng curriculum, is the use of lifelong learning (LLL) modules or courses. The practice project USAGE, Upskilling Agricultural Engineering in Europe, has developed LLL opportunities on SA technologies tailored to agricultural engineers and practitioners (USAGE 2023; Vidric et al. 2023). USAGE conceptualized and developed diverse educational programms and products mainly on topics of the digital transformation. The short and tailored manner of USAGE LLL products fits ideally with cross-competences required in AgEng bachelor and master conceptualizations. USAGE produced a handbook that lays out the pathway to combine different LLL modules to a joint AgEng master program of the affiliated unitversities (Paulus et al. 2022).

3 RESULTS AND CONCLUSION

The present paper underlines that through a rigorous approach, academic competence formation in AgEng is possible. A stabilized curriculum on bachelor and master level, based on expertises, cross-competences and experience helps the discipline to address real world challenges and gain more visibility. Such stabilization will foster synergies and collaboration between sectors, rather than feeding unnecessary competition.

Emerging SA technologies require ever more cross-competences and interdisciplinarity. SA technologies refer to core capacities of AgEng and provide therefore an important incentive to strengthen and modernize the curriculum of AgEng. The discipline often suffers the competition with experts from other domains; which is normal when a domain is open to interdisciplinary approaches. The focus needs to remain on the primary goal, i.e. the technological soul of biological production systems, determining the exact role and contribution of each actor in the various steps of the process.

As a discipline AgEng needs for stable curriculum based on clearly defined segments (expertise, cross-comp, experiences) and flexible upgrading opportunities to cope genuinely with real world requests. Thus as a complete and transversal discipline, AgEng is able to develop far-reaching visions for technologies in productive biosystems. Considering the experiences from the project USAGE underlines how innovative LLL courses and learning modules can successfully teach cross-competences in the realm of AgEng and SA in comparably short time.

4 SUMMARY AND ACKNOWLEDGMENTS

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Fostering individual learning types on online learning platforms to strengthen students' competencies

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ABSTRACT

The availability of video lectures and hybrid formats in higher education has increased significantly due to the COVID-19 pandemic. Predominantly, however, instructional content has simply been translated 1-to-1 into video formats regardless of effectiveness and students' needs. Interaction and diversity in content delivery were often missing. This practice paper presents an ongoing investigation on how lecture content can be presented within an online learning platform in order to meet the

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individual learning types of students and to address actual usage behaviour, potentially enabling a positive effect on learning outcomes. By creating learning paths, students can choose from different content modes, such as interactive video material, image hotspots and text material, and internalize the content according to their individual learning types. In addition, surveys are used to identify their motivation for choosing the content form as well as the extent to which this was helpful to successfully complete examination assignments. The results of the surveys will be analyzed and used for further improvements. Through the targeted use of different content modes, the positive aspects of online teaching can be furthered while strengthening the knowledge of the students individually in order to best prepare students for the complexity of a future work environment.

1 INTRODUCTION

1.1 Current situation

Facing the COVID-19 pandemic, virtual lectures and online learning have become a key element in education (Tsang et al. 2021). In this context, online learning is not a new approach; in fact, it has been used for years (Kentnor 2015). Through systematic design processes, online courses for education have been developed years ago, using technologies such as websites, learning portals, video conferencing, and mobile apps in the most efficient way. In this regard, the effectiveness of online learning has been generally demonstrated (Allen and Seaman 2013).

Nonetheless, it is important to emphasize that, until the outbreak of the pandemic, conventional academic education was mostly based on face-to-face classes and the appropriate technical equipment and flexibility were largely lacking. For many instructors, the transition to online or hybrid teaching was abrupt and under high time pressure. However, in order to maintain the continuity of higher education, it has been essential for universities and colleges to adopt online learning as a primary modality. Traditional learning methods were no longer sufficient to meet the demands of the learning process (Tsang et al. 2021). According to reports from the Technical University of Berlin, that is seen as representative for other technical universities in Germany, lecture content was often simply transferred 1-to-1 into video formats. This possibly limits interaction and feedback opportunities, lowers motivation and doesn’t sufficiently support long-term learning if not considered carefully (Avila, Maria, and Genio 2020). An initial study by the Department of Micro and Precision Devices has demonstrated the need for alternative approaches in online teaching as the demand of students have changed in response to the new circumstances effecting teaching formats prospectively (Marckwardt et al. 2022). Preparation for the real working life and the mix of subjects requires the ability to think holistically, to take initiative, to be confident, to be creative, to be a lifelong learner, to be agile, and to have appropriate methodological skills, which should be taught as key components (Kamp 2020).

To enhance these competencies, appropriate teaching approaches are needed that offer choice and flexibility, promote multi- and interdisciplinary learning, and also teach responsibility, methodological skills, and ethical foundations. In order to take

advantage of the positive developments in online teaching in recent years and to respond to the lessons learned about knowledge acquisition through online formats, it is necessary to adapt virtual presentation of information to individual learning types. A pure 1-to-1 transfer of content is not sufficient to meet the individual needs of students. Research shows a broad variety of approaches investigating important factors in the design of teaching formats, especially for online teaching. In particular, this includes the consideration of learning techniques, the learning environment, and individual characteristics of personality and learning such as the incorporation of personal learning types (Y. Wang et al. 2008). These investigations emphasize that the teaching formats need to maintain and awaken students' motivation in learning, as this correlates directly with learning results (Chang 2005).
Since the current state of research indicates that self-regulation learning and freedom of choice in learning, as well as the stimulation of curiosity through e.g., novel learning formats, significantly enhance student motivation, the aim of this research approach is to find methods strengthening these needs. The findings are also supported by our own survey data (see Fig. 2), showing that students explicitly stated that they found the free choice of learning formats particularly motivating. They tested out the formats motivated by curiosity and the possibility of self-determination in terms of time when acquiring knowledge.

Not all aspects of successful and sustainable learning can be directly addressed through the way knowledge is imparted. The possibility of self-regulation can be given by the mediation via online platforms, as well as the selection of the appropriate format for individual learning types. Vester, among others, categorizes learning types into auditory, visual, haptic, and intellectual, which are used in many educational contexts (Quilling 2015). Moreover, Kolb sees learning styles not only as individual preferences, but also as a learning cycle of an ideal learning process that includes the incorporation of concrete experiences, reflected observations, concept formation, and active experimentation based on the concept (Staemmler 2006).

To implement these teaching formats, we have drawn inspiration from Kolb's learning style model. Despite there are ongoing scientific discussions surrounding the model (Dantas and Cunha 2020), it nevertheless provides an intuitive framework for developing learning formats and enables potential comparisons with other studies. In order to have flexible options for implementation, in the approach presented, a hybrid learning platform is used in this context, which supports the processing of socially relevant topics through transdisciplinary collaboration (Marckwardt et al. 2022). As part of the learning concept of an online learning platform, the results presented here should help to identify which learning formats are best suited to support the individual needs of the students in online environments. Consequently, this practice paper presents research investigating how lecture content can be presented within an online learning platform in order to meet the individual learning types of students and to address actual usage behaviour, potentially increase learning motivation and enabling a positive effect on learning outcomes.

2 MOTIVATION AND DEVELOPMENT OF METHODOLOGY

Many new options have emerged as a result of the major teaching changes forced by the pandemic. As a result, established teaching methods are now competing with innovative formats. Both approaches have advantages and disadvantages, and together they form an even wider range of options. Lecturers are therefore confronted with the question of which formats can be maintained in which ratios, which formats support student motivation, and which optimize learning success. In order to answer these questions, surveys and test implementations have been conducted to observe and measure the actual learning behaviour and needs of students.

2.1 Motivation: Surveys on students' learning preferences

Due to the mentioned changes in teaching, it is necessary to record the current teaching situation as well as the motivation and preferences of students in order to enable efficient and long-term learning, adapted to individual needs.
Thus, a brief preliminary survey was carried out, which was used as a basis for a more detailed survey with regard to preferred formats, the motivation for selecting courses and formats, the desire and the possibility to actively participate in defining the content as well as personal learning goals and learning types. Some of the questions asked in the first survey were repeated in more detail in the second survey. Whereas the first survey offered binary response options and a simple choice of options, the second survey was much more detailed and included a rating system (0 to 5, not relevant to very important). The surveys were made available via the online learning platform ISIS and linked in the respective lectures; participation was voluntary. The coverage of the survey was 25 participants out of a total number of 5500 students at the faculty. It can be assumed that only a fraction even knew about a potential participation in the survey. The actual reach can only be roughly estimated at a few 100 students. Thus, no precise statement can be made about the actual response rate. The resulting biases are discussed in the results section. Response rates in the module-based surveys were representative, with approx. 45% participation rates. The results of the preliminary survey indicated that students would like to use a hybrid (online and presence combined) teaching format. The majority (52%) reported a preference for knowledge transfer through interactive participation and hands-on practical tasks. In addition, more than one third (36%) indicated that their motivation to learn had decreased due to isolation during the COVID-19 pandemic.

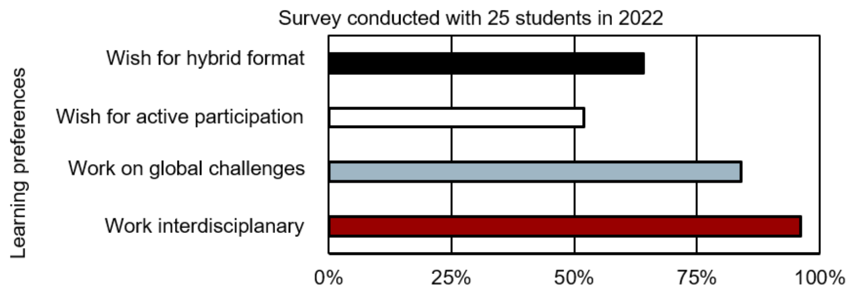

Figure 1: Preliminary survey on students' learning preferences conducted during 2022

These findings suggest that 64% of the students would embrace hybrid teaching opportunities to learn interactively in a community with the benefits of both face-to-face and online teaching. Further results showed that 96% of the students are motivated by interdisciplinary work and co-design of course content.
The second study showed that 92% of the students now choose their courses more on the basis of how well they fit in on time with other preferred lectures as well as into their private lives. This emphasizes both the need for flexibility and the significance of ensuring appropriate implementation, which aligns with the current research situation. In addition, the teaching format (4.1) was quite important to them now that there is an option. However, the possibility of getting a very good grade (2.6) was not as important as expected. This was also shown in the question about what they were proud of after completing a module, where the knowledge acquired (4.0) was more important to them than the final grade (3.3). The motivation to take part in a course increased more in courses having the hybrid format (3.9) than in the face-to-face format (3.6). Students even rated the online-only format as more demotivating (3.0). The degree to which students like to attend different course formats depends on the degree of interaction and practice. For example, they like to attend exercises, practical courses and tutorials. In comparison, lectures and project work are less popular with them. Goals of students were also analysed. 81% of students reported that they had personal learning goals for the current semester, while they focus more on hard skills than on soft skills. Nonetheless, the majority of students (55%) reported that they had never been encouraged by instructors to set personal learning goals. The other half (45%) also reported that 78% of them had not been asked about the achievement of their personal learning goals at the end of the module. It was observed that students only partially achieved their learning goals, whereas, according to them, the more interactive the teaching format was, the more likely students were to achieve their personal learning goals.
In the last part, the desires of students were analysed. The interest of the students in interaction was high. They would like to interact with the teaching staff, for example, when setting up project assignments (4.0). The desire for projects related to global challenges ranked second (3.7) after social issues (3.9), and the desire for interdisciplinarity was also high (3.8). Respondents preferred face-to-face events for interactive courses and hybrid events for mediated formats such as lectures.

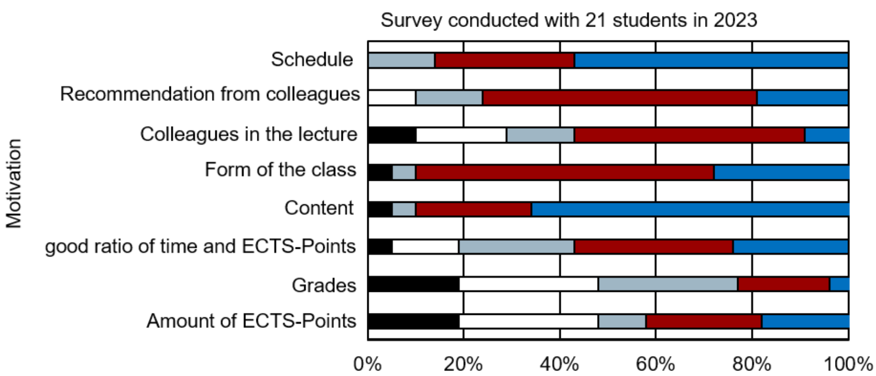

Figure 2: Second survey on students’ motivation conducted during

The many options that have become more available in teaching also increase the use of individual learning types, so these were also included in the second survey. In a self-assessment, students indicated that they are most likely to learn in an auditive (4%), optical-visual (48%), haptic-kinesthetic (17%) and cognitive-intellectual way (22%). In particular, the optical-visual type, which represents the largest group, was able to benefit from the teaching formats that were partially implemented on a compulsory basis during the pandemic.

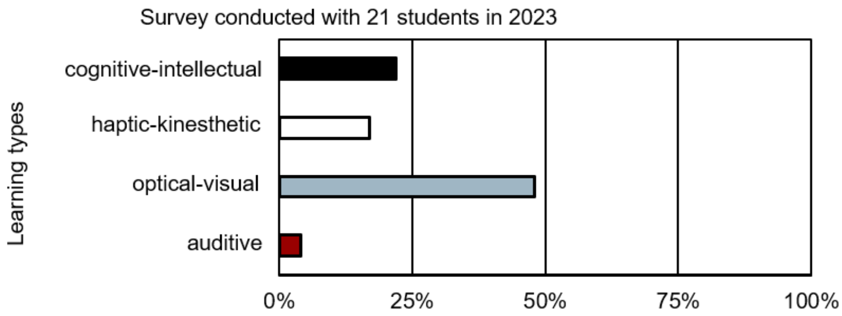

Figure 3: Second survey on learning types

In summary, it can be said that students prefer a complementary mix of teaching formats within a course module, that hybrid formats and the associated flexibility are perceived as very attractive, and that online teaching and the associated possibility of consuming a wide range of courses has also awakened a greater desire for interdisciplinary teaching.

Most of the data collected is based on surveys and self-reporting, which introduces inherent biases that cannot be completely eliminated. Due to the voluntary nature of survey participation and the limited coverage of the surveys, sampling bias cannot be entirely ruled out. While efforts were made to generate a broad sampling range, it is important to note that the demographic data predominantly represents one faculty within the university. Furthermore, the real usage data is restricted to specific module groups within the department. Additionally, common biases such as response bias exist, limiting our insight into actual behaviour and lacking contextual information. To mitigate response bias, control questions were included in the surveys, and real usage behaviour was recorded and compared with survey responses, although it should be acknowledged that real user behaviour also relies partly on self-reporting. Consequently, the overall results are limited and should be analysed individually. Nevertheless, the implemented countermeasures enable an evaluation of the methodology employed, which can be applied to other modules.

2.2 Observations after COVID-19 pandemic

Following the end of pandemic teaching restrictions and the return of students to university campuses, the Department of Micro and Precision Devices restructured established teaching methods and redundantly mixed them with newly developed methods as inverted classroom concepts. The well-established digital learning platform *"Information System for Instructors and Students (ISIS)"* at the

Technische Universität Berlin was used to test students' preferences and acceptance of different teaching formats. This platform could be used to present the learning content and to carry out the surveys on the procedure and use in accordance with data protection regulations. Since the platform is well known to the students, an easy, error-free use of the content could be assumed.

Students could decide for themselves whether to use asynchronous materials for self-study at any time or synchronous lectures at fixed times. The content was identical. Lectures were also offered in a hybrid format, allowing students to choose whether to attend online or in person. For data protection reasons, learning analytics at the TU Berlin are relatively limited, but some usable data traces are available. The data traces available only allow measuring the frequency of use of the online offerings as well as the number of different users and can be resolved in the smallest increment of one day. The videos were not downloadable, so they had to be watched online. Illegal screen casts cannot be ruled out. The sharing of materials by several students cannot be ruled out either. This imposes an indeterminable uncertainty into the data. However, it is assumed that these individual cases in the cohort size still allow significant results to be obtained.

This led to the following observations: Of the students enrolled for the exam, an average of 65% regularly used the synchronous option, with variations depending on the subject area, with the significantly larger proportion of these (70% of synchronous participants on average) preferring online participation. The use of the asynchronous option varies from 78%-84%, depending on the subject area. The number of different asynchronous users remains relatively constant throughout the semester, but the frequency of use increases, as expected, during the examination periods.

It is therefore evident that there are students with purely asynchronous learning styles (approx. 30%), students with purely synchronous learning styles (approx. 20%), and students with a mixture of the two learning styles (approx. 50%). However, the database generated by this procedure does not allow a clear separation between the groups, as some students may adapt their behaviour depending on the subject area, and no correlation with self-perceived learning type or learning success is possible. Thus, the procedure was adapted to integrate a new methodology described below.

2.3 Methodology: Development of learning paths to support different types of learning

The surveys and observations mentioned above underline the wish for teaching formats that are flexible to individual time schedules and needs contributing to self-regulated learning. Both teachers and students see the advantage of being able to give or follow lectures in this way from anywhere, which contributes positively to flexibility and individual lifestyles. Students become self-directed learners and learn both synchronously and asynchronously. However, online learning also has many disadvantages, the most important of which is that knowledge is only imparted on a theoretical basis and learners cannot apply what they have learned in practice. There is a lack of interaction and collaboration with other participants, as the content is often simply transferred 1-to-1 into video formats (Maatuk et al. 2022). Hybrid formats at least offer consultation with the lecturer, but active interaction and practical handling of teaching material is not possible. Individual learning needs and goals are hardly taken into account, which is underlined by the survey results presented above.

Consequently, in this concept paper different methods of presenting information are derived according to existing strategies for different learning styles. Thereby, interaction, collaboration between students and a motivation for long-term learning shall be promoted. The aim of the didactic approach is to address these learning styles in the best possible way by including different online teaching formats. Not only is the consideration of individual learning styles advantageous, but the possibility of active, independent decision-making to select a particular learning format has been shown to contribute to motivation in learning (Morisano et al. 2010). Additionally, it supports the basic psychological need to perform tasks out of enjoyment (Rohlfs 2011).

To investigate the usage behaviour, the course "Processes and materials in micro- and nanotechnology" was used, as it provides a sufficiently broad cohort of students as well as a variety of online materials. In the adapted course of several lecture series, concise, thematic chapters of the video lectures were extracted and presented via branching scenarios as an inverted classroom method. Accordingly, knowledge was imparted according to the scheme listed below (see Fig. 4). After each learning unit, questions were asked about acceptance and usage behaviour. To test the approach, a lecture on thin film technology was created. First, information was presented on how to create the individual subject code, which will be needed later to match the generated information with the result of the test. The first part of the lecture on physical vapour deposition (PVD) was as usual presented as a video.

For the second part of the course on chemical vapour deposition (CVD) students could choose between different presentation formats. The first choice was also a video of the lecture slides with voice-over. The second option was an interactive video, where the video was interrupted to ask questions about the content to interact with the user. Besides, the content could be acquired by reading a provided book chapter on the topic independently. The last form, supporting the auditive learning type, consisted of listening to 21 minutes of the podcast “Chaosradio Podcast” 128 on diamonds.

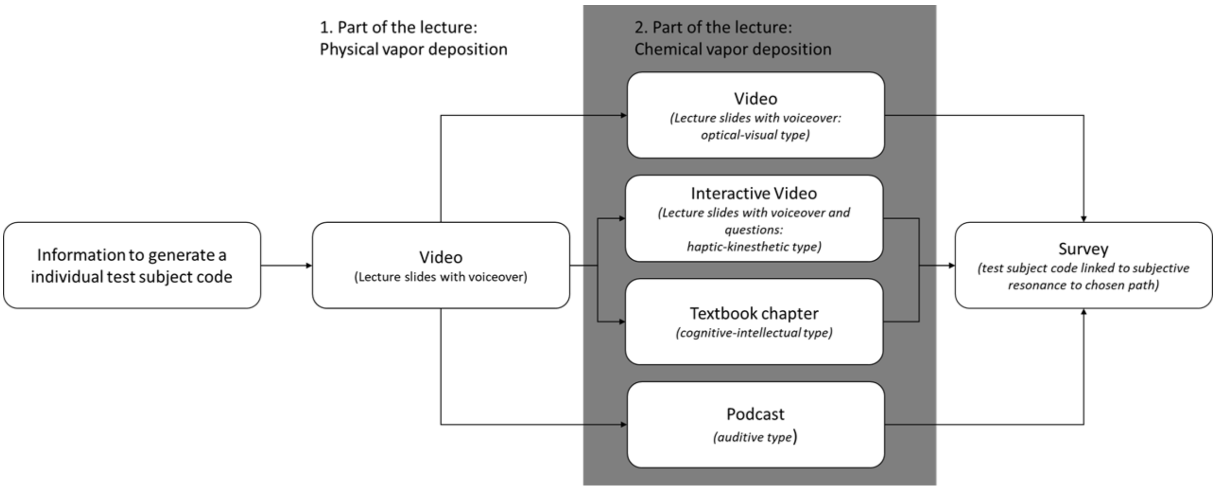

Figure 4: Scheme of lecture with branching for inverted classroom depending on the individual learning type

After the end of the lesson, a survey was conducted, which included the aforementioned questions and associated them with an anonymous respondent code. The survey on the selection of the mentioned teaching formats shows that the 18 questioned students primarily chose the interactive video (61%). The students' learning types were unevenly distributed among auditive (0%) optical-visual (33%), haptic-kinesthetic (44%), and cognitive-intellectual (22%) types. 83% of the participants indicated that the teaching format they selected was appropriate to their learning type. The remaining stated they were curious to learn and experience a different learning format. In summary, the students have essentially chosen the interactive format, which also actually fits their perceived learning type. The question remains whether this will have a positive impact on their learning outcomes in the long term.

3 SUMMARY AND ACKNOWLEDGMENTS

The past few years under pandemic conditions have shown that changes in teaching and in the way of learning can sometimes come quickly and unexpectedly. Nevertheless, the implementation in teaching has often been positive under the given conditions, but also provide great potential for the future. It is important to make skilful use of the new possibilities offered by the improved technical equipment in universities and the new mindset in the implementation of hybrid teaching formats.

The first results of this study show that students are grateful for the use of different formats and find it very engaging. The empowering approach and the interaction with the teaching material are highlighted as particularly positive. Further research with a larger number of students is needed to find out whether the teaching formats also have different effects on learning success in terms of grades and long-term knowledge building. So far, medium-term knowledge acquisition has been analysed by randomly repeated queries of previously presented lecture content. This has provided initial insights into the relationship between teaching format and individual student learning type. However, the question remains whether knowledge is retained in the long term. Based on these initial findings, it will be investigated to what extent the presentation form in online environments has a positive effect on learning effectiveness during intermediate tests and the exams. The forms of presentation that are optimally correlated with the respective learning types and successful results will in the future be integrated into the hybrid learning platform described in (Marckwardt et al. 2022). For this purpose, exams at the end of the semester will be used to check whether students who have primarily used teaching formats that are positively correlated with their learning type outperform their fellow students. This analysis is already being prepared for the current semester.

Above all, long-term learning and drawing connections through interaction with the learning material, critical reflection, and an understanding of how best to acquire knowledge will prepare students to solve complex problems in their future professional lives. The authors would like to acknowledge the active contribution of the company The Coding Machine, specifically to Mr. Gregory Rocher and Mr. David Négrier for supporting the development of the online gathering platform.

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EELISA Credential: THE RECOGNITION OF COMMITMENT AND IMPACT IN THE ADDRESSING OF SOCIETAL CHALLENGES IN THE EELISA ALLIANCE

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ABSTRACT

EELISA Credential is a unique recognition process provided to EELISA students, professional and alumni who are part of the mission-driven EELISA communities and reflects the commitment and impact level achieved in the addressing of a societal challenge.

The EELISA Credential is an individual, progressive environment on which students collect badges. These badges are acquired after verifying the achievement of an educational outcome level after participating in community's educational activities. A badge represents the unit of learning acquisition and impact that corresponds to an educational outcome. It is reflected in the EELISA Credential which itself refers to an impact level and a Sustainable Development Goal (SDG).

The impact level represents the badge measurement scale. In the EELISA Credential, there are 5 levels of impact (discovery, knowledge, engagement, action, transformation) that correspond to learning objectives relative to SDGs.

The education activities proposed by EELISA Communities are defined around a societal challenge defined by a problem owner (faculty, students, local communities). Each activity is centered in 1 or 2 SDGs, and recognizes a maximum of 4 badges.

Through the involvement in the activities of EELISA Communities, students enrich their EELISA Credential in areas addressing Sustainable Developments Goals (SDGs), progressively improving their capacity for understanding, action and transformation.

In this practice paper, we will present the requirements for activities to be part of the EELISA Credential, representative and successful activities, the Quality Assurance system, the lessons learnt in the process of implementing the credential and how EELISA Credential will evolve in the future.

1 EELISA ALLIANCE AND THE EELISA ROADMAP TO THE EUROPEAN ENGINEER

The European Engineering Learning Innovation and Science Alliance, EELISA, with its acronym inspired by Elisa Zamfirescu —the most international of Europe's pioneering women engineers [1]—, brings together nine universities from seven different countries, with 180,000 students, 16,000 academics and researchers, and 11,000 other staff, with the aim of promoting a model European engineer and architect combining technical competence and societal impact [2][3].

EELISA aims to transform European higher education while strengthening links between engineering and society by re-inventing the "European engineer", democratizing engineering education, evolving interdisciplinary engineering learning, encouraging knowledge, skills and technology transfer, fostering inclusiveness and diversity and making a real impact on society following the 2030 Agenda for Sustainable Development and the SDGs.

EELISA Aliance partners are Budapesti Műszaki és Gazdaságtudományi Egyetem (Hungary), École Nationale des Ponts et Chaussées (France), Friedrich-Alexander-Universität Erlangen-Nürnberg (Germany), İstanbul Teknik Üniversitesi (Turkey), Scuola Normale Superiore (Italy), Scuola Superiore Sant'Anna (Italy), Universidad Politécnica de Madrid (Spain), Universitatea Politehnica din București (Romania) and Université Paris Sciences et Lettres (France).

The four pillars of the European Engineers as envisioned by EELISA are [4]: 1) High level of scientific, theoretical and digital skills; 2) Addressing Sustainability; 3) Interculturalism: an engineer embracing the European project; and 4) Business and communication skills and critical thinking: practical and applied knowledge.

As academic tools for recognition, the institutions of the EELISA alliance have agreed on the following [5]:

- EELISA credential: the "academic materialization" of innovative and transformative learning experiences produced by EELISA Communities and recognizes the student's engagement in activities framed within the Sustainable Development Goals (SDGs).
- EELISA Supplement: an EELISA mobility "certificate" designed to encourage and reward academic mobility (physical, digital or hybrid) within the alliance. It is attached to a bachelor or master/engineering degree and is awarded to students having completed at least 6 ECTS in mobility per academic year either accumulated or carried out in one go with internships, studying abroad, participating in activities linked to a community, or through courses included in the EELISA joint catalogue.
- EELISA Degree: initially a label for the joint degrees offered within the alliance, realising shared visions for the European Engineer profile, learning outcomes and methodological elements (scientific level, approach focused on learning outcomes, creation of a multicultural, multidisciplinary student experience anchored in societal challenges). In the long-term, the EELISA Degree will be a degree awarded with European recognition for a study program jointly organized by EELISA partners.

2 EELISA CREDENTIAL

2.1 Introduction and background

The EELISA alliance has established Communities as a major asset for engaging internal and external stakeholders and transforming member institutions with new forms of collaboration. EELISA Communities allow students, staff, faculties and external stakeholders to work together on multidisciplinary issues and put societal challenges at the center of cooperative activities between alliance members [6].

EELISA Communities produce activities ("learning experiences") that are innovative and transformative learning experiences for the participants, primarily the students. The EELISA Credential is the "academic materialization" of these experiences – it is a passport, certified, fraud-free and IT-based, in which the student collects the evidences (“badges”) of participation in the activities of the EELISA Communities.

The general principles of the EELISA Credential are as follows:

- It is built on the whole of an educational pathway in a progressive way
- It is built from the activities belonging to one or more Communities
- It is individual (whereas a Community has a collective scope).
- It is awarded to students and possible alumni, not faculties
- It materializes/recognizes ability to contribute to solving societal challenges addressed by Communities and as defined by the UN Sustainable Development Goals (SDGs) [7]

The EELISA Credential is not a diploma/degree or an educational pathway in the sense that it does not address a profession or a disciplinary field. It is a recognition of learning outcomes acquired in performing activities related to specific SDGs *[8]*.

2.2 Requirements for EELISA Credential

The EELISA Credential opens for the student upon participation in his/her first activity of an EELISA Community. The EELISA Credential expresses the achievement of educational outcomes by participating in activities of EELISA Communities [6].

One activity is formed by a set of badges. A badge corresponds to an impact level in one of the SDGs educational outcomes.

For each SDG, the activity designer can define 5 possible badges, each corresponding to a level of impact (discovery - knowledge - commitment - action - impact), that leads to a total number of 85 badges associated to the 17 SDGs (section 2.3).

Each activity is associated to at least one SDG, thus resulting in the number of badges associated to each activity. The SDGs, the learning outcomes and the number of badges associated to an activity are given in the Activity description. Each activity is centered in 1 or 2 SDGs and recognizes a maximum of 4 badges.

Each activity, according to its nature, its ambition, its theme can allow each participant to validate one or more badges. It is up to the activity designer to select which badge(s) a participant is eligible for. The activity designer proposes the badge(s) to be awarded to the community coordinator/leader, as well as the proposed assessment method.

Activities of the EELISA Credential have to comply with the following requirements:

1) Belonging to an EELISA Community and being validated by the Community coordinator.
2) International: it is offered to all EELISA students with no significant barriers, if carried out locally, an effective and international exchange of data or knowledge is demonstrated, student teams shall be formed by students of more than one EELISA university, co-tutorship of Bachelor and Master Thesis from two EELISA universities.
3) Society-oriented: must be outward-looking/practical (thus differentiating itself from a regular course), this may be through its subject, participation of stakeholders...

2.3 Impact levels

One of the most innovative and transformative aspects of the EELISA Credential is the introduction of learning outcomes linked to a measurement of the societal impact that is product. With this impact measure, EELISA alliance intends to motivate and recognize the commitment and impact produced by the actions of the students in their pathway to resolve societal challenges.

Each badge corresponds to both an educational outcome and to a level of impact. 5 impact levels have been defined in the SDGs educational outcomes according to [7] (*Fig. 1*):

- Level 1 = DISCOVERY: activities aiming at networking, generating community and generating awareness (simple participation in a conference as a listener)
- Level 2 = KNOWLEDGE: knowledge and thinking skills necessary to better understand the SDG and the challenges in achieving it (5 cognitive educational outcomes)
- Level 3 = COMMITMENT: social skills that enable learners to collaborate, negotiate and communicate to promote the SDGs as well as self-reflection skills, values, attitudes and motivations that enable learners to develop themselves (5 socio-emotional educational outcomes)
- Level 4 = ACTION: activities aiming at developing behavioral competences to produce solutions for fulfilling the mission of the community (5 behavioural educational outcomes)
- Level 5 = TRANSFORMATION: impactful activities resulting in change, with demonstrable and quantifiable KPIs.

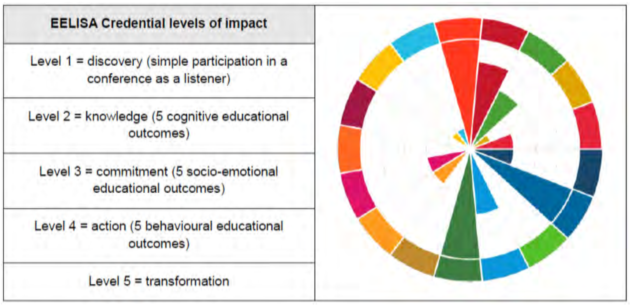

Fig. 1. Levels of impact of the EELISA Credential and corresponding 'SDG radar'

2.4 Guidelines for designers of EELISA Credential activities

As a framework for thinking about activity designers, we can recommend the assessment methods in *Table 1* for the EELISA Credential's SDGs educational outcomes levels.

Table 1. Levels of educational outcomes for EELISA credential

Level	EELISA Credential outcome	Key words for educational outcomes	Example of an associated learning experience	Examples of assessment methods	Collective component required
Level 1	Discovery / engagement	Exposure, superficial and beginners' knowledge	Conference / Roundtable	Attend a conference	None
Level 2	Knowledge	Understand, Evaluate, Know	Cycle of conferences / MOOC	MCQ, Essay, Reflective practice	Low
Level 3	Commitment	Connect with, Reflect, Contextualize, Feel	Lectures with applied tutorials	MCQ, Reflective practice, Problem solving, Essay	Moderate

		responsible			
Level 4	Action	Plan, Implement, Influence, Speak, Organize, Promote, Create	Group work with production of deliverables	MCQ, Essay, Problem solving, Practical work	Strong
Level 5	Transformation	Implement, Probe, Deployment, Build	Impactful project with demonstrable KPIs (funds raised, populations reached, stakeholder engagement...)	Objective and measurable demonstration of impact	Very strong

2.5 EELISA Credential format

The EELISA Credential template issued is shown in *Fig. 2*. The design was driven by several aspects: with a naked eye, an external stakeholder should visualize immediately the SDGs and impact level achieved by the students, and it should include a summary of the activities in which the student has participated. The EELISA Credential comprises:

a) Front page – It includes the identification of the student, University, a summary of the impact levels as defined in EELISA, and an 'SDG-Impact Radar' chart. It represents the impact levels achieved by the student and to which SDG they correspond. SDGs are represented as 17 equiangular sectors. Thus, after a quick inspection, it is clear if the student has focused on activities of a few SDGs (few spokes will appear) and the impact level (length of the spokes).

b) Back page – A description of the EELISA Credential, number of activities completed by the student, maximum impact level achieved, which SDGs the student has worked with and which EELISA Communities have proposed the activities where the student has been enrolled.

c) Annex – Information the activities carried out by the student is shown, including activity name and short description, dates, ECTS (if relevant), SDG addressed.

Front page　　Back page　　Annex

Fig. 2. Template of EELISA Credential

The EELISA Credential is signed by the EELISA President, and the badges issuance is approved by the Academic Coordinator of the institution in charge of the activity.

3 EXAMPLES OF ACTIVITIES IN THE EELISA CREDENTIAL

Some of the activities proposed by EELISA Communities in the framework of the EELISA Credential and available in the EELISA Communities portal [9] are:

- International Seminar on Urban Mobility (EELISA On the Move)
- AIRONE – Artificial intelligence in Robotics in Extended Reality Seasonal School in Pisa (Augmented and Virtual Reality for ENGineering – AVRENG)

- Mathematical Approaches for SDGs (MATH4SDG) (SSERIES: Science for Sustainably Envisioning Reality and Information for an Engaged Society)
- Think Tank European Space Agency (Sustainable BCC. Sustainable Buildings, Cities and Communities (SUSBCC))
- HACK|BAY – A hackathon for everyone – challenge to improve children's radiology experience (AI4HEALTH)
- Scaperoom 2022 – A vigorous escape from linear economy via international collaboration (Circular EELISA)
- Hackathon: Designing a sustainable Campus (Designing a Sustainable and Decarbonized University (DISCOVERY))
- Tech for Sustainability Campaign and Hackathon (STAR – Sustainable Territories through Action & Research)
- Global Challenge Action (Ethics, Social Commitment & Entrepreneurship)
- EELISA Science Fiction Short Stories Contest (Tech Diplomacy & Intl Cooperation)
- EELISA Days Challenge – Extreme Event Game (WATER in an era of change)

4 KEY FIGURES OF THE EELISA CREDENTIAL

The key figures representing the status of the EELISA Credential to date are [10]:

- Number of credentials issued: **1231**
- Number of activities organized: **80**
- Stakeholders, problem owners involved: **69**
- Number of badges vs SDG: **1821** badges have been issued. As shown in *Fig. 3*, the concentration of badges around 4-5 SDGs clearly represents the areas where EELISA partners are willing to have a sustantial impact.

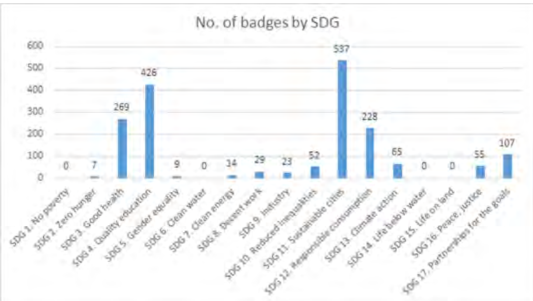

Fig. 3. Number of badges vs SDGs

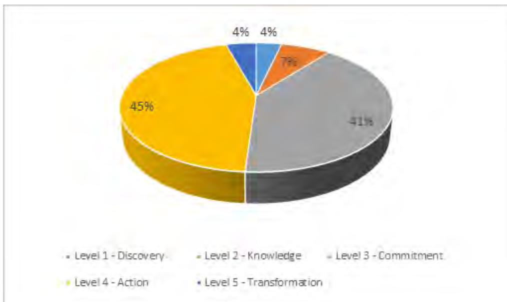

Fig. 4. Number of badges vs impact

- Number of communities and people involved: a total of **46** EELISA Communities involving **2453** people are currently (mid 2023) active in EELISA.
- Number of badges vs impact (*Fig. 4*): 85% of the badges correspond to Level 3 – Commitment and Level 4 – Action. In these first years, few activities tackling Level 5 – Transformation have been implemented.

5 LESSONS LEARNT

During the set-up and first years of the EELISA Credential, we have learnt some lessons valuable to be shared:

1) Communication of the EELISA Credential to be known by students and faculty: Issuing badges for the EELISA Credential did not emerge as a driver of student engagement in activities offered by EELISA communities. It was the themes, the international aspect and the "non-routine" pedagogical mode that triggered their engagement, as well as the connection to the SDGs. For the teachers, the fact that the activities they proposed in the framework of the communities could lead to the delivery of badges for the EELISA Credential is an added value, a positive side effect but not a primary one. It is not trivial to make something extracurricular exist, given the fact that students are focused on the value of their traditional degree and their busy schedules. However, there is a space for a form of recognition of skills, knowledge and know-how acquired outside the traditional academic curriculum. Communication on the added value of the EELISA Credential must capitalize on what is expected by many companies (autonomy, taking initiative, working in groups), and on the expectations of the young generation of students in the 21st century (sustainable development, search for meaning, sensitivity to societal and environmental issues). It is on these expectations that we must make progress in terms of communication on the EELISA Credential.
2) Students' involvement: the academic load of students is quite high. Although the variety, interest and complementarity of the activities proposed by communities, the participation of students has been very limited. Not all the degrees recognize the ECTS achieved in an activity as part of the curricula. In addition, more innovative activities focused from problem or challenge-solving approaches would be appealing to have students on-board, as well as the possibility to cooperate in an international and multicultural environment with other students will enrich their experience. As well, it is important to communicate the realization of the activities in social media, in order to motivate potential students for upcoming activities.
3) IT tool/wallet: to store and stack-up the badges of the EELISA Credential and make them shall be shareable, an IT platform is required. Students should have a central site to look up the status of their credential and be able to share their achievements with whomever interested. When designing the EELISA Credential and its subdivision into badges, we were inspired by (among other things) open badges [11]. Open badges are digital certifications that recognize and validate the skills acquired by an individual. Open badges can be easily shared on social networks and professional platforms, allowing individuals to showcase their skills and experience to a wider audience.
4) Attraction of problem owners: in order to propose new challenges and make the EELISA Credential sustainable in the long-term, active problem owners must participate. These problem owners can be found in external stakeholders, society and non-governmental organization must be invited. As well, the fidelization of stakeholders to get involved in the definition of new challenges will naturally lead to increasing number of badges producing the highest impact (transformation). Synergies of the cooperation between students and stakeholders shall enrich the learning outcomes of the activities.

5) Recognition of EELISA Credential by the society and companies: once the EELISA Credential gets known by society as a differential and transformative experience, it will boost the number of students involved in the activities of the EELISA Communities and will attract interested problem-owners with appealing challenges to be solved.

6 CONCLUSIONS AND FURTHER STEPS

In this paper, we have presented the EELISA Credential, which represents the "academic materialization" of innovative and transformative learning experiences produced by EELISA Communities and recognizes the student's engagement in activities that contribute to solving societal challenges framed within the SDGs.

The architecture of the EELISA Credential and its component badges is similar to the European Union's initiative on micro-credentials. Micro-credentials are envisioned as a new way to recognize and verify mainly informal learning achievement that any person has earned [12][13]. Micro-credentials are also associated to lifelong learning, where individuals might diversify learning pathways during the professional career.

The European Micro-credential is an initiative of the European Union to promote the recognition and validation of competences acquired throughout life, using a micro-training and certification approach [14]. It is a key EU initiative to strengthen the recognition of competences on a European scale, promoting a standardized and transparent approach to lifelong learning, certification and validation of competences.

There are many parallelisms between the EU micro-credential and the EELISA Credential badges: they are obtained through different modes of education/training, focusing on specific knowledge/competences, and the learning objectives underlying each activity are standardized.

The EELISA alliance intends to explore, in the coming years of its existence, the convergence of the EELISA Credential with this EU initiative, using this opportunity to highlight the knowledge and skills to be acquired in the field of sustainable development through the links between the SDGs and the EELISA Credential badges.

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Integrating Augmented Reality Technology into Condition Based Monitoring Laboratory Experiments (Practice)

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ABSTRACT

This paper examines the pilot phase integration of Augmented Reality (AR) technology into a Condition Based Monitoring (CBM) engineering taught module. Students participate in a laboratory cycle within the CBM module, engaging in multiple experiments on a weekly basis, including Shaft Alignment, which provides meaningful, industry-relevant experience in an engineering environment. During the laboratory sessions, multiple pairs of students complete the experiment simultaneously on multiple custom engineering rigs. The Shaft Alignment procedure, although very relevant to industry needs, is also complex and time consuming, with students often struggling to complete the task within the designated laboratory time. AR technology has been introduced into this module to improve the experimental instructional design, improve the learning experiences for the students and reduce unavoidable practical delays during the experimental cycle. Existing experimental procedures have been implemented as AR content including re-crafted instructional content, multimedia content (videos and images), and custom CAD data overlaid on the engineering rigs as AR reference geometry.

The newly-introduced AR-based experiments were completed by multiple students over the course of a number of weeks in April and May 2023. Students provided participant feedback via survey before and after engagement with the AR technology. Test groups were aligned within the class as comparators in terms of using existing non-AR procedures and new AR-enhanced procedures.

The outcomes from this pilot phase are presented in this paper, with particular focus on student and lecturer experience, knowledge gained in the context of content creation pathways for future AR integration and increased productivity within the laboratory.

1 INTRODUCTION

1.1 Background to Pilot Project

The Condition Based Monitoring (CBM) module is a Year 2 module in the Engineering Reliability Management Bachelor of Technology programme in School of Mechanical Engineering in Technological University Dublin Bolton Street Campus. Within the laboratory cycle for this CBM module, students complete multiple practical engineering experiments of varying levels of complexity.
A pilot project began in December 2022 with the aim of developing and integrating Augmented Reality (AR) content to enhance existing experimental completion processes.

1.2 Benefits of AR Integration

AR-enhanced learning and training scenarios provide an interactive learning experience by allowing students to engage with virtual objects in a hands-on manner. They can manipulate and interact with virtual machine parts, observe their functionality, and perform simulated tasks. This interactivity fosters active learning, improves retention, and helps students develop practical skills in a safe and controlled environment.
When dealing with complex machinery, safety is paramount. AR-enhanced training enables students to practice and gain familiarity with equipment without the associated physical risks. They can learn to identify potential hazards, understand safety protocols, and practice correct procedures. This helps reduce accidents, prevent damage to expensive machinery, and build confidence before working with real equipment.
AR-enhanced content can provide real-time guidance and feedback to students during training. Virtual overlays can display step-by-step instructions, highlight specific components, or provide contextual information about the machinery. This guidance helps students navigate complex procedures more effectively, troubleshoot issues, and perform tasks accurately, enhancing their learning and performance, providing detailed context and information in situ, creating a situated learning environment in which students can feel comfortable.
The immersive and interactive nature of AR-enhanced training captivates students' attention and enhances their engagement. By blending the virtual and real-world elements, AR creates an exciting and motivating learning environment. Students are more likely to stay focused, enjoy the training process, and feel motivated to explore and master complex machinery concepts.

1.3 Experimental Selection

A specific shaft alignment experiment was chosen from the CBM module which gave sufficient scope for AR-enhancement, AR geometry integration and instructional design capacity, whilst being also of appropriate duration to allow a suitable student experience using AR hardware.
The complete experiment involves several discrete processes including:

- mounting and calibrating laser alignment units
- measuring misalignment
- physical re-aligning of shafts

The experiment also includes multiple, pre-requisite setup tasks including preparing coupling jaws and mounting shaft units. To provide a suitable completion time for the shaft alignment experiment, the overall process was sub-divided into multiple, discrete experimental steps.

Figure 1 shows the assembled apparatus for the experiment, including (a) fixed motor housing, (b) shaft coupling housing, (c) movable bearing mountings and (d) laser alignment equipment.

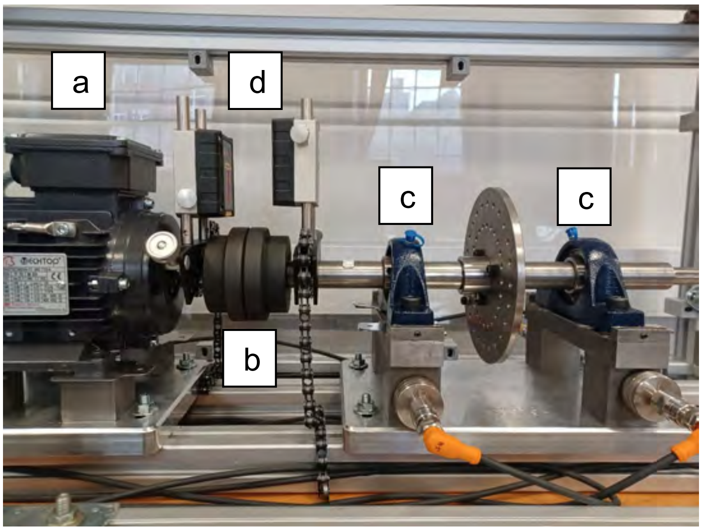

Figure 1 Experimental Rig

This sub-division of experimental process allowed the AR content authors to decide on the specific entry point at which students would engage with the AR-enhanced stage of the experiment. As the tasks are composed of discrete steps that lead students through each process, this enabled a degree of flexibility in the deployment of the AR-enhanced learning scenarios as tasks can be reorganised and re-arranged based on feedback and changes to module requirements etc.

This sub-division of experimental process also provided the AR content authors with a useful testing opportunity in AR content authoring, whereby the pre-requisite setup tasks were also enhanced with AR content. The usefulness and instructional design capacity of these enhanced setup tasks was evaluated before considering the larger core elements of the experimental process. These initial setup tasks were not included in the live engagement sessions by the students.

2 PRACTICE

2.1 AR Hardware

The Microsoft HoloLens 2 device is a head-mounted AR-enabled device, or 'headset'. The device operates in an untethered state, not connected physically to additional hardware, and it accesses data solely via Wi-Fi. The inbuilt headset hardware includes head-tracking gyroscopic sensors, inward-facing eye-tracking sensors and outward-facing cameras for hand- and gesture-tracking.

AR data is projected onto the visor at the front of the headset to provide the AR immersion effect to the wearer. AR content is developed for this headset using a variety of software development platforms, including Microsoft Dynamics 365 Guides, Unity and Unreal Engine.

Both device battery life and re-charging time are important concerns with respect to future perpetual rollout of HoloLens 2 devices. During the engagement phases of this pilot project, the battery status of devices was monitored carefully throughout all experimental engagement. In a future live implementation, a bottleneck or disruption to access of a set of laboratory-specific HoloLens 2 devices, due to re-charging time, would be a critical usage factor.

2.2 AR Content Authoring

Microsoft develop an AR content-authoring application, Microsoft Dynamics 365 Guides ('Guides'). All 'Guides' content is stored in the cloud and streamed 'on-demand' to the headset while in use. The specific cloud storage mechanism is specific and nuanced; it can only be developed within a Microsoft Dataverse cloud storage implementation. This implementation has perpetual maintenance cost implication, which is not insignificant in the academic realm. Guides has been specifically designed by Microsoft as a 'no-code' development platform to ease the authoring process and includes two separate development environments: a 'desktop-authoring' application and a 'headset-authoring' application.

AR content is initially created on the Guides desktop-authoring application, where the narrative for explicit instructional content is crafted and subdivided into parent 'tasks' and child 'steps', and where bespoke multimedia and CAD content is added. When sufficient content has been developed on the desktop-authoring application, additional custom, contextual AR integration is developed specifically on the headset-authoring application. This allows the author to specifically overlay, or integrate, the AR geometry onto the real-life base context.

The Guides desktop-authoring application provides a collection of pre-built AR data commonly incorporated within AR-enhanced scenarios. The provision of this data has the potential to reduce the amount of custom CAD data required from the AR author.

The workflows of placing, overlaying and aligning AR data onto the real-life base context using the AR headset is a relatively simple task but is not ideal. It requires the manual intervention from the content author, where the time spent coordinating content can be significant, and the precision available in placing and aligning content is variable at best.

2.3 CAD Data Development

The chosen shaft alignment experiment uses a variety of mechanical equipment elements, including the mechanical rig itself, laser alignment equipment, and additional adjustment tools and equipment. Equivalent CAD data, or CAD models, of this equipment are required from an appropriate 3D modelling application and are subsequently exported or translated to appropriate AR-specific content. The level-of-detail required for AR model display is significantly less than that required for general manufacturing purposes of that same specific equipment.

The choice of CAD application is not constrained exclusively to one specific application brand. In the specific context of Guides workflow, Microsoft recommend the use of Blender, a free 3D modelling, sculpting, and rendering application. Blender is available on free-to-use, open-source licensing model and is very commonly used within the visualisation and rendering industry. However, Blender modelling workflows are not optimal compared to other applications within the engineering realm.

SolidWorks is a commercially-licensed, closed-source, parametric CAD application which is more commonplace in the engineering realm. Functionality within SolidWorks allows geometry to be created and edited more appropriately than in Blender. The creation of appropriate CAD models in SolidWorks also provides the ability for the author to simultaneously retain a manufacturing-specific level-of-detail for the CAD model data as well as a simplified AR-specific level-of-detail. SolidWorks provides AR data export functionality which allows the export of geometry directly from SolidWorks to a format which can be imported directly into Guides. This SolidWorks functionality negated any requirement to use Blender and provided a much shorter completion time in the development of the relevant CAD geometry and AR data for this pilot project.

2.4 Polygon Count Considerations

The level-of-detail of CAD geometry displayed by the headset has an effect on the performance of the headset whereby geometry of high polygon count can be unnecessarily processor-intensive whilst not yielding, or providing, equivalent representative gains for that high level of detail. Microsoft provide appropriate guidelines and polygon count recommendations for use within the Guides environment displayed on a HoloLens 2 device. These guidelines also provide certain workflows for specific software, with the aim of reducing the overall polygon count. The proposed guidelines are provided for Blender and SolidWorks.

An alternative ‘configuration-based’ polygon reduction workflow was implemented in SolidWorks by the authors which was more appropriate in terms of manipulating native SolidWorks CAD geometry.

2.5 AR Learning Scenario Development

Microsoft provide suggested strategies of instructional content design specifically tailored to Guides, including direct actions in language use and the specific nature/psychology of instruction. Some of the strategies also combat against some of the in-built software limitations of Guides itself. The design strategies were considered and purposefully used in the development of the content for this pilot project.

The AR-enhanced version of the shaft alignment experiment was divided into two primary Guides learning scenarios, and each learning scenario was further sub-divided into multiple parent tasks and child steps, mimicking the existing physical experimental instructions.
The required laser alignment equipment interacts with a tablet device and a related tablet application, from which multiple screenshots were extracted. Experimental actions using the mechanical rig which were intricate and/or difficulted to verbally describe, were captured via video-recording of live demonstration. The resulting image and video content were integrated into the relevant points of each Guides learning scenario.
Branching strategies were also implemented within the instructional design to provide opportunities for task review, and also for repetition of iterative experimental steps, which presented as authentic engineering learning within the experiment.

2.6 CAD equivalent of Experimental Equipment

The CAD geometry of the mechanical rig used in the shaft alignment experiment was originally developed natively in SolidWorks for manufacturing purposes in the design phase of the lab equipment. However, the data was relatively polygon-intense as a result of its manufacturing level of detail. A process was implemented in SolidWorks to reduce polygon count by 'configuring de-featured, simplified CAD components' while still retaining sufficient levels of detail appropriate for AR integration overlay. This defeaturing process presented only minor workflow obstacles or constraints, as the original geometry had been created very appropriately in its original form.
The CAD geometry of the laser alignment equipment was sourced from the equipment OEM provider. Whilst this CAD geometry was very well defined and accurate, it was provided in a neutral CAD file format, which did not provide, or allow for, an opportunity to apply the same SolidWorks defeaturing process. As a result, it was required to remodel the laser alignment units in SolidWorks in a simplified form, using the original CAD data as a baseline reference. The fine grain level-of-detail was not required in this new CAD model, and an appropriately-simplified model was developed.

2.7 Authoring and Testing of AR-enhanced experiments

The authoring and development of initial AR-enhanced instructional content involved multiple iterations and revisions to the instructional narrative, CAD data and multimedia content. A series of engagement testing sessions were proposed to trial the initial learning scenarios, and gain insights on the quality of these initial revisions.
The current, standard, long-standing student experience for the shaft alignment experiment involves:

- an initial live instructor demonstration of the experiment on a specific demonstration rig
- the division of the student cohort into teams of four students per available experimental rig
- the subsequent completion of the experiment by each team using traditional paper-based instructions

The first phase of engagement testing sessions was carried out in multiple sessions, each session comprising two students and each student completing the experiment individually on a separate rig using individual HoloLens 2 headsets. All queries, interactions, comments and insights from each student were recorded individually; this initial overall set of comments and insights were captured from three separate sessions comprising a total of six students. All Guides content was revised, informed accordingly by the recorded comments and insights.

A second phase of engagement testing was carried out, again in multiple sessions, using eight students from a different, but related, programme. The rationale was to investigate if students from a related field could still engage with a technical engineering experiment, guided with AR enhancements. Subsequent to this phase, all Guides content was revised again, informed by the new comments and insights taken.

Finally, a third phase of engagement testing was carried out using eight staff members from the School of Mechanical Engineering, each having varied technical expertise in the engineering realm and in the software/technology realm. Upon completion of this third testing phase with a subsequent appropriate revision process, we concluded that the development and delivery of the AR-enhancement experience for the chosen experiment was sufficiently close to optimal.

2.8 Revision of AR-enhanced content

The revision strategies applied to the Guides content included:

- update of narrative content
- clarification of instructional text
- amendment of screenshots, photographs and related imagery
- clarification of specific experimental process
- addition and removal of specific parent tasks and/or child steps

It was clear from the phased approach of revision management that whilst the AR content authors had sufficient expertise to develop the content from an instructional and technical perspective, certain instructional elements would regularly, and incorrectly, infer existing knowledge or meaning which was not explicitly or clearly explained.

The insights gained from the iterative design and testing will form the basis of future authoring of AR enhancements of existing experimental processes within the programme.

3 RESULTS

3.1 Findings

3.1.1 Reduced Volume of Student Queries

In all engagement testing sessions, the AR-enhanced mode of experimental completion yielded a substantially lower volume of mid-experiment student queries, in terms of experimental issues. Students using the AR-enhanced data were able to engage with, and navigate across, the provided instructional data, without requiring the previously-encountered high levels of lecture intervention.
This also consequently reduced the required mid-experiment activity of the supervising instructor.
This allowed the supervising instructor to engage in more meaningful discussions with the students in terms of the relevancy of experimental process, in essence the 'why' rather than the 'how'.
This presents as the obvious advantage in implementation of AR-enhanced learning scenarios, providing:

- maintaining the quality of experimental output
- the student with a more appropriate learning experience
- the instructor with a means to reduce repetitive, time-consuming fundamental or basic level queries regarding the experimental process.

3.1.2 Lack of Concurrent Multi-user Interaction

In the non-AR-enhanced mode of experimental completion, multiple students would work together in teams to complete the experiment on a single rig.
Currently, the Guides application does not provide functionality to allow multi-user access to a concurrent AR session. This lack of concurrency requires a single user to complete the AR-enhanced equivalent in isolation on a single rig.
As the AR interactions cannot be shared between users, and due to a resulting lack of team collaboration between students, certain experimental issues and mistakes made in the experimental process were amplified; in many cases, a simple reduction in available physical hands contributed to multiple equipment malfunctions.
This lack of concurrency can be considered a major flaw in the overall testing experience and also can be considered a major compromise in the experimental process. This is one of the biggest disadvantages in that is reduces what is a collaborative task between students to a solo task, albeit one enhanced by AR.

3.1.3 Bottleneck in Content Reading

Currently, the Guides application only provides functionality to output text-, image- and video-based data as accessible formats of instruction as part of any AR enhancement.
However, the Guides application does not explicitly provide functionality to output audio-only instruction as part of the AR-enhancement.
An audio alternative would reduce the requirement of the students to read every AR experimental step. This was perceived as a stumbling block, or bottleneck, to certain students in their completion of multiple experimental steps. The bottleneck did not

manifest in interpretation but simply in time spent considering the narrative; a more appropriate instructional environment for certain students would allow them to simply listen to the instructions.

3.1.4 AR Hardware Induction

In the first phase of engagement testing sessions, students were not given a ‘pre-flight’ induction with regard to operation of the HoloLens 2 device. They were introduced to the device at the start of the experiment, which purposefully presented feedback in terms of the most obvious interaction bottlenecks with the device.
A short video introduction was crafted in advance on the second phase of engagement testing sessions which was subsequently provided to students well in advance of their first experiences of the headset. This pre-emptive video content provided the students with more awareness of the AR-enhanced environment and experience. The initial headset setup time and general student interaction with the headset during the completion of the shaft alignment experiment were positively impacted in the subsequent phases of engagement testing sessions.

3.2 Recommendations

Whilst the current status of the pilot project can be considered a resounding success, impactful constraints in this format of AR-enhanced learning are evident; a lack of concurrent user interactions and standalone audio support.
Alternate AR content-authoring platforms, Unity and Unreal Engine, do provide audio support. A future intention of this pilot project is to develop similar AR-enhanced experimental processes within the existing laboratory space using these alternate development platforms. This will allow further student engagement testing to compare user interactions and user experience between the content authored in different platforms.
Resources exist within alternate development platforms to develop concurrent, multi-user interactions. This is a critical research element within the pilot project, but the technical details in developing the required AR-enhanced content are significant.

MAPPING THE SUSTAINABLE DEVELOPMENTAL GOALS AND STUDENT PERSPECTIVES ON SKILLS DEVELOPMENT USING ALTERNATIVE ASSESSMENTS FOR ENGINEERING EDUCATION

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Keywords*: Student perspectives, Student-created videos, in-class debates, assessment, sustainability engineering education.*

ABSTRACT

Student-created video and in-class debate were introduced in the assessment of education for sustainable development (ESD) in an environmental engineering module. This work was undertaken with a group of structural and civil engineering students in their stage 3 of study for a level 8 degree. There were 63 students registered for this course: 40 civil and 23 structural. Prior to any intervention, a linking exercise was undertaken to map the words in the module descriptor to the Sustainable Development Goals (SDGs). This informed the design of the assessments.

After completion of the respective assessments, student surveys were used to understand the student perspective on the use of these techniques. Students perceived acquisition of skills was analysed and qualitative questions relating to the attainment of knowledge were reviewed.

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The Student-created video was a summative individual assessment worth 5% of the final mark while the in-class debate was a formative assessment where students were required to work in groups of 4/5.

INTRODUCTION

1.1 Education for Sustainable Development

Education for Sustainable Development as a subject is a relatively new idea. It emerged in the late 1980s (Hopkins, 2012) due to the revolutionary advent of the sustainability concept by the Brundtland Commission in 1986 (Brundtland, 1987). It is complex and multifaceted. The 17 sustainable development goals (SDGs) are interlinked at every level and it is difficult to separate one from another. Educating engineers for the future cannot be achieved without incorporating the SDGs at every opportunity.

1.2 Mapping the SDGs

When mapping SDGs to academic modules, a direct link can be made between SDGs and some disciplines (e.g. Water and Environmental Engineering, Food Sciences). The connections between other disciplines and the SDGs might be less obvious or might need further consideration. Therefore, the first step is to identify the SDGs that are most related to the module description, its learning outcomes, and syllabus. A useful tool to help with linking SDGs and modules is SDG keywords (ITS, 2021). SDG keywords were originally compiled for the purpose of mapping research discipline areas and their outputs to SDGs but have become increasingly used for the purpose of mapping modules to SDGs (Adams et al. 2020) In this work, the learning outcomes for the module were linked to the SDGs using keywords as outlined in (ITS, 2021).

1.3 The use of student-created video and in-class debate in assessment

Both formative (in-class debate) and summative (student-created video) assessments were used in this work. Assessment fulfils a number of important functions in the learning process. These functions include but are not limited to, allowing students to determine if they have attained a satisfactory level in a given study area and facilitating educators to identify if students ability to study specific subjects (Ashwin et al., 2020). Formative assessments are desgined to show students how they can improve and do not contribute to any academic credit while summative assessments are used to indicate knowledge and skills at a given point in time and to provide academic credit (Yorke, 2007). In this work in-class debate was operated as a formative assessment and the student-created video was a summative assessment.

Cebrián Bernat et al. (2019) has made a number of recommendations in relation to the use of both formative and summative assessment in ESD: comparison of different assessment tools against sustainability competences; design and test assessment tools with ESD principles of critical thinking, collaboration and teamwork in mind. In this instance the use of group work in the in-class debate contributes to developing the skills of teamwork and collaboration. Technical knowledge acquisition, and time required for video production are some of the skills that have been reported as learning outcomes from sudent-created video (Campbell et al., 2022). Students have reported that video creation is useful in reinforcing concepts taught during class (Greene and Crespi, 2012). Positive impacts of student generated videos are reinforcement of learning, more active learning, more engagement and enjoyment of learning.

2 METHODOLOGY

2.1 Linking the SDGs to the Module Descriptor

The module descriptor was scanned to highlight the main keywords (e.g. sanitation, wastewater, water, sewage, pollution, water quality) and these were matched with the SDG keywords obtained from the list developed in (ITS, 2021). The matching exercise has resulted in a number of SDGs, some less obvious than others, that may be related to the module. Following the linking of the SDGs to the module descriptor, the assessment of sustainability attributes was designed.

2.2 Formative and summative assessments for ESD feedback

Surveys for both assignments were developed in line with those devised and validated by (Watson, 2013). Students were given the option of completing the survey using online Microsoft forms or in hard copy having completed the respective assessment.

The research questions posed were (1) What knowledge do students have about the SDGs after the in-class debate? (2) What knowledge do students have about water sustainability after the student-created video assignment? (3) What skills have been developed through the assignments?

In this survey students were asked to rate their responses to quantitative statements relating to the assessments using a Likert scale where a score of 1 indicated “Strongly disagree” and a score of 7 represented “ Strongly agree”. The quantitative data which were analysed here, were those associated with the acquistion of critical thinking skills.

The quantitative statements that were posed which will be analysed here in relation to the in-class debate were:

a. Participation in the in-class debate improved my ability to analyze the potential impacts of the sustainable development goals
b. Participation in the in-class debate improved my ability to evaluate the importance of each Sustainable Development Goal in an Engineering Context

For the student-created video, the quantitative statements were:

c. Participation in the video assignment improved my ability to analyze the potential impacts of the sustainable development goals
d. Participation in the video assignment improved my ability to evaluate the importance of water engineering with respect to the Sustainable Development Goal in an Engineering Context

Students were asked to answer qualitative questions relating to the acquisition of knowledge from the assessments.

For the in-class debate they were asked

e. Why are the sustainable development goals important?
f. Outline what you have learned from the debate

While the student-created video questions were:

g. Why is the sustainability of water important?
h. Outline what you have learned from this assignment

3 RESULTS

3.1 Linking the SDGs to the Module Descriptor

It can be seen from Table 1 that some SDGs may seem more relevant than others but all related SDGs as per the matching exercise are being initially included. Following this, the targets of the goals selected are included so that targets/goals most related to the module's learning outcomes can be examined.

Table 1. Linking SDGs with keywords of Environmental Engineering Module

Module Keywords	Related SDG	Target
Access to clean water and sanitation	SDG3: Good Health and Wellbeing	3.9
Affordable drinking water, clean water, contaminated, improving water, Inadequate water, infrastructure, Rivers, sanitation, sewage, sustainable water management, sustainable	SDG6: Clean water and sanitation	6.3, 6.4, 6.5, 6.6

withdrawal, water resources management		
Sustainable consumption	SDG8: Decent work and economic growth	8.4
Pollution, waste, solid waste, waste management, Water	SDG11: Sustainable cities and communities	11.6
Waste, water, water pollution, water supply, reduce-reuse-recycle.	SDG12: Responsible consumption and production	12.2, 12.4, 12.5
Climate change	SDG13: Climate Action	13.3
Fish, biodiversity	SDG14: Life below Water	14.1, 14.2

This exercise highlighted the broad range of the SDGs which were encompassed in the module which led to the use of the in-class debate to incorporate as many of the SDGs as possible. The student-created video was used to focus on SDG 6 while encouraging students to incorporate the other goals where relevant.

3.2 Student Perspectives on assignments

There were 37 responses to the in-class debate survey while there were only 17 responses to the student-created video questionnaires.

Overall, Statistical analysis of the quantitative statements in the survey showed that students perceived that there was an improvement in their critical thinking skills. A score of 4 on the Likert scale represents “Neither agree or disagree”. Any value above this is leaning towards “agree”. All of the mean values for the statements analysed were above 4. Responses to statements a. and b. in relation to the in-class debates above both generated a mean of 5.2. For statements c. and d. in relation to student-created videos were slightly lower at 4.8 and 4.7 respectively. These results suggest that students perceptions were that their analytical and evaluation skills relating to the SDGs generally, and specifically with respect to water sustainability were improved by participation in both the in-class debate and the student-created video assignments respectively.

The main theme that emerged from the qualitative statement e. Why are the sustainable development goals important? in relation to the in-class debate was “future” (13 instances). Other themes were “life” (5 instances) and “planet” (8 instances).

For statement f. Outline what you have learned from the debate the interconnectedness of the goals was evident from multiple responses. One example stated:

“Each goal is unique but effect each other. They are all inter-linked”

The recurring themes in response to the question g. Why is the sustainability of water important? relating to the student-created video were “future” (7 instances) and “protect” (2 instances) and “health” (2 instances). The overall lesson learned appeared to be that the sustainability of water was important in order to protect health in the future.

Responses to h. Outline what you have learned from this assignment (video) demonstrated an understanding of the importance of water treatment:

“I have learned a lot about water treatment planrs (sic) and the importance of water.”

An awareness of the importance of protecting water was also demonstrated:

“There are many ways to protect the water environment however a lot of investment and planning is required”

Qualitative analysis of responses shows a frequent occurrence of the words found in the mapping of the SDGs exercise.

4 SUMMARY AND ACKNOWLEDGMENTS

In summary, this work has been very useful in informing the assessment of ESD. Student perspectives demonstrated that they felt that they had developed critical thinking skills by participating in the student-created video and more so, in the in-class debate.

The initial use of an innovative formative assessment was useful in developing students collaboration and communication skills. It also provided the educators with confidence in the students’ SDG knowledge to complete the summative student-created video assignment.

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STUDENT ENGAGEMENT IN SUSTAINABILITY ISSUES THROUGH VIDEO PRODUCTION: A CRITICAL CONSCIOUSNESS-BASED APPROACH TO ENGINEERING EDUCATION

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ABSTRACT

The formation of engineering students should prioritize both technical skills in engineering and a critical awareness of the designed world. This qualitative methods study aimed to analyze the extent to which a teaching approach, based on the in the integration of Freire's critical pedagogy and Multimodal literacy frameworks, promotes first-year engineering students' development of critical consciousness. Drawing from Paulo Freire's work on critical pedagogy, the critical consciousness framework emphasizes that individuals and their practice in community awaken

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critical awareness of their surroundings, including the interconnectedness that exists between economic, social, political, cultural, historical, and environmental factors. To this end, we designed an activity for students to research and create videos that illustrate the interconnectedness that exists between these factors. The activity provided an opportunity to build, express, and shape their thoughts regarding the connections between the designed world and its implications on society (i.e., who wins, who loses, who is involved, etc.). Preliminary analysis identified that multimodal video production allowed students to investigate and express their own interpretations of socio-political and sustainability issues related to the use of precious minerals, specifically cobalt. Furthermore, students included descriptions of their proposals for reducing child labor abuse in cobalt mining and identified the environmental impacts of excessive use of cobalt in technological devices. Overall, this research suggests that integrating critical consciousness and multimodal literacies can be an effective strategy for promoting engineering students’ formation in terms of engineering design, literacy, sustainability, and social awareness.

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1 INTRODUCTION

In order for engineering students to see the complexity of their roles as engineers in the world, it is important to participate in critical pedagogies that provide them with the tools to critically analyze the world around them (Freire 1997). Freire and Macedo (2005) argued that in order to critically analyze the world around us, it is important to engage in practices that contribute to meaning- and sense-making through different modes that allow for codification and decodification. Thus, the use of multimodal literacies becomes essential in the education of engineering students as multimodality involves the extraction, construction, integration and critique of information through various modalities such as conceptual frameworks, drawings, symbols, text, images, sounds, and gestures, among others (Frankel et al. 2016).

This study contributes to the expanding research on engineering literacy and the ethical professional development of engineering students deepen to become critical and informed participants in the world's decisions. This paper, which is part of a larger research project, was guided by the research question: *to what extent does a multimodal activity based on the extraction and use of cobalt promote the development of critical reflexivity among engineering students?* The activity sought to engage students in the development of short informational videos about the extraction and use of cobalt. This research demonstrates the impact of multimodal artifacts and the significant role these play in the engineering curriculum and the development of students' critical consciousness.

2 CONCEPTUAL FRAMEWORK

2.1 Critical consciousness

In 1970, Paulo Freire discussed the significance of critical pedagogy, which encourages individuals to examine how they are situated within systems of oppression that are shaped by their historical and cultural contexts (Freire 2003; Giroux 2010; Shor and Freire 1987). By reflecting on themselves and the systems they are part of, individuals can "read the world" and gain an understanding of their power and options for action (Freire and Macedo 2005; Freire 1985). Freire called this process the development of critical consciousness, which is not a linear process but rather a framework for self-actualization that enables individuals to envision new futures for themselves and achieve self-liberation through action and reflexivity (Freire 2003). Freire (1997) outlined it as a five-stage, where the first stage was the "semi-transitive state." In this stage, individuals are preoccupied with survival and have limited critical perception of their surroundings and lived realities. The second stage involves the "transitivity of consciousness," where individuals can reflect on themselves, their lived realities, their roles and responsibilities, and work with others to replace their disengagement with commitment to change (Freire 1997). The third stage is called "naive transitivity," where individuals are characterized by "an over-simplification of problems; by a nostalgia for the past; by underestimation of the common man; by a strong tendency to gregariousness; by a lack of interest in investigation, accompanied by an accentuated taste for fanciful explanations; by fragility of argument; by a strongly emotional style; by the practice of polemics rather than dialogue; by magical explanations” (Freire 1997, 18). This stage is critical because the individual may rely on argumentation, oversimplification, or simple reasoning that prevents critically thinking about what lied beneath the surface (Shudak and Avoseh 2015). This is also a critical stage to overcome because the individual’s critical thinking may still be fragile and easily fall back to a state of semi-transitivity. Therefore, engaging in a more in-depth analysis of the world is necessary to continue toward the fourth stage, “critical transitivity,” which is characterized by a deep analysis of problems and an increase in agency (Freire 1997). Finally, the fifth stage is “critical consciousness,” which represents an awakening of critical awareness from a critical educational effort. In this paper, we draw from Freire’s framework of critical consciousness to describe how students used multimodal literacies to engage in a critical analysis of content knowledge, writing and communicating the impacts of modern technologies on society, and to highlight the ways in which multimodalities provide students with the ability to question social, cultural, historical, and political factors in engineering.

2.2 Multimodal Literacies

Engineering literacy practices build not only on scientific literacy practices but also draw from a complex combination of communication standards, symbolic representations and computational simulations and calculations (Wilson-Lopez et al. 2022). For example, disciplinary literacy in engineering may involve the use of specific vocabulary, tools, and knowledge, as well as the ability to communicate effectively within specific fields of expertise (Wilson-Lopez et al. 2022; Shanahan and Shanahan 2012). These practices also include visualizing models, interpreting data, identifying information sources from various disciplines, using specialized language to convey ideas, and utilizing other expertise specific to the discipline (Cejka, Rogers, and Portsmore 2006; Robinson and Kenny 2003; Wilson, Smith, and Householder 2014). It is noteworthy that engineers apply their own individual beliefs, values, and ways of knowing, doing, and being when developing their literacy practices (Mejia and Revelo 2022). Thus, engineering is not only a cognitive process, but also an embedded set of social practices and tools within the field of engineering (Pawley 2009; Mejia, Revelo, and Pawley 2020).

Given that engineers produce and interpret different oral, written and symbolic representations through literacy practices, it is important to think about the role that multimodal literacies play in the development of critically conscious engineers. Multimodal literacies involve the use of different modes of meaning (i.e., written, oral, visual, etc.) that are used for meaning making (Mills and Unsworth 2017). Multimodal literacies in engineering are important because engineers require multimodal representations (i.e., symbols, equations, visual aids, schematics, writing, simulations) for sense- and meaning-making. Moreover, multimodal literacies allow engineering students – those that are on their path toward becoming engineers – to develop a critical understanding of the world around them.

Multimodal literacies allow individuals to read the word – and the world – through “critical perception, interpretation, and rewriting of what is read” (Freire and Macedo 2005, 24). Thus, we argue that multimodal literacies in engineering are necessary for helping engineering students develop their own critical consciousness about the world that surrounds them through the use of multimodal semiotics (i.e., signs, symbols, and any other elements of language) (Mills and Unsworth 2017). Multimodality has been widely explored in the sciences and science education (Unsworth et al. 2022; Tang and Moje 2010; Jones et al. 2020; Klein and Kirkpatrick 2010), but more work on the benefits of multimodality and literacy are needed in engineering education research.

3 METHODOLOGY

This study involved 40 first-semester engineering students (8 teams of 5 students each) who were enrolled in a course that analyzed the impact of modern technologies on society. An activity based on Multimodal Literacy was developed for this research, which required students to create a video using Animaker to raise awareness among society, engineers, and government about the critical issues arising from the extraction and use of cobalt. Animaker (https://www.animaker.com/) is a free access software that allows users to create videos, incorporating different multimodal representations such as images that can modify gestures and facial expressions in addition to audio, voice, music, and text.

The research design employed a qualitative methods approach. The data was collected from students’ final videos (i.e., artifacts), classroom discussions in the form of field notes, and audio transcripts. The analysis began with open coding using NVivo 12 to divide, examine, and compare the information in search of similarities and differences (Strauss and Corbin 1990). Through repeated analyses, the categories were defined through a second coding process, which involved a coding protocol (Saldaña 2015) developed from the codes obtained during the first round of coding. Both researchers reviewed the analysis separately and discussed discrepancies until they reached agreement. To answer the research question, special attention was given to three relevant aspects: (1) the types of representations used by the students through multimodalities, (2) the critical issues that the students included in their videos regarding the extraction and use of cobalt, and (3) the students’ suggestions to reduce critical problems related to the extraction and use of cobalt.

4 RESULTS

In this section, we present the results of the analysis of the construction process of the teams’ videos. The first section describes the type of multimodal representations the teams considered important to include in the construction of their videos to express their thoughts on the critical issue of cobalt extraction and use. Regarding the second and third sections, it should be mentioned that based on Freire’s (1997) concept of critical pedagogy, the students had the freedom to include the critical elements they considered relevant. Here we present the most noteworthy aspects of the videos using representative examples obtained from the data. Future work will further expand on all of these characteristics.

4.1 Multimodal representations used by the teams

The teams utilized at least two out of the four possible modes (video, audio, written text, images) offered by the software to construct their videos (Figure 1). Specifically, three teams employed four modes of representation, three teams used three modes, and two teams used two modes. This indicates that the teams recognized the importance of incorporating multiple ways to convey their interpretations. Moreover, the results also indicate that combinations of multimodalities were the preferred method for students to convey messages related to the social impacts of cobalt use and extraction.

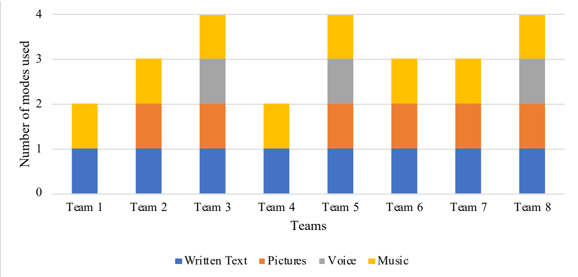

Fig. 1. Types of multimodal representations used by the teams

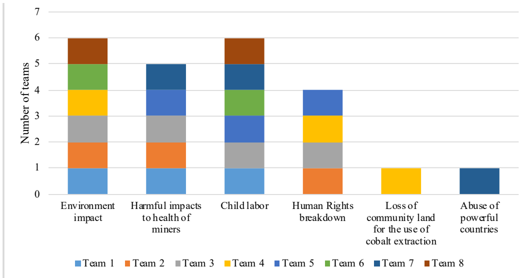

Fig. 2. Critical impacts included in the team's videos

4.2 Critical impacts of cobalt use and extraction included in the team's videos

Through the analysis, we were able to identify six critical aspects that were recognized by the students (Figure 2). Six teams identified the impact to the environment and child labor, while five teams highlighted harmful health impacts on miners. Additionally, four teams addressed the aspect of the violation of human rights. One team, in particular, addressed the loss of land and the displacement of the community, which was seized by the government or companies for cobalt extraction. Another team explicitly pointed out the abuse of power by more powerful nations over those with less power, making the comparison between the Global North and the Global South.

4.2.1 Environmental impact. Six out of the eight teams included descriptions associated with the environmental impact of the extraction and use of cobalt. For instance, Team 6 created a video that included a section with the image of a person throwing a big rock at trees depicting the destruction of the surrounding environment. This image is accompanied by descriptions associated with both direct and indirect environmental damage due to cobalt extraction (Figure 3). Team 4, for example, included a written description in their video that highlights how cobalt extraction systemically affects different elements of nature, including people's health. The text read:

[Cobalt extraction] Pollutes water, air, and soil leading to decreased crop yields, contaminated food and water, and respiratory and reproductive health issues.

Fig. 3. Video section of Team 6

The excerpt from this video demonstrates the analysis done by the students and the social, environmental, and health implications of cobalt extraction. Nonetheless, it is important to note that the students did not specifically indicate who is at fault, and who is the most affected. Instead, the text generalizes the impacts of cobalt extraction. Other teams included images of a cloudy sky and written text of the effects of climate change due to emissions created by jet engines that use cobalt as part of their systems. Thus, in some instances, the students problematized the use of cobalt in everyday technologies and not only on the extraction of the mineral.

4.2.2 Harmful impacts on miners' health. Five teams included in their videos descriptions associated with cobalt miners' health. For example, teams 3 and 4 included images and phrases that highlighted the high levels of radioactivity generated at the extraction zones affecting the health of the miners. Below is an excerpt from the text included by Team 3:

In mining regions, scientists have made note of high radioactivity levels. 70% of cobalt resources are located in high-risk contexts. Exposure to cobalt may cause weight loss, dermatitis, and respiratory hypersensitivity.

The text shows how students tried to identify the health repercussions for those that worked in the mines, particularly miners. The students also mentioned the health impacts of cobalt mining on people living near mine sites such as asthma-related problems, thyroid problems, nausea, and vomiting.

4.2.3 Child labor. Six out of the eight teams included descriptions expressing their concern about the presence of, and sometimes forced labor of, children in cobalt mining activities. For example, Team 5 included a message written on top of an image of two people talking that mentioned the following: *6-year-old children are working in these [cobalt] mines.* Images were also used to convey the message, which created a huge impact on students. For instance, Team 7 included images showing mothers and children extracting cobalt from mines, accompanied by a "thumbs down" symbol, demonstrating their disapproval. In a later section, they included the following text: *Reduce and eliminate child labor across the world.*

4.3 Proposals to reduce adverse effects

All Teams proposed solutions to reduce adverse impacts of cobalt (Figure 4). The proposals related to governmental actions included, seven teams suggested better regulations to protect miners and minors, while five teams proposed rescuing children from forced labor. Regarding device users (i.e., society in general), three teams advocated for reducing and recycling usage, and four teams suggested raising awareness. five teams proposed device modifications to reduce cobalt use, while another five teams emphasized action by companies selling such devices. Finally, two teams identified the necessity for collaborative efforts.

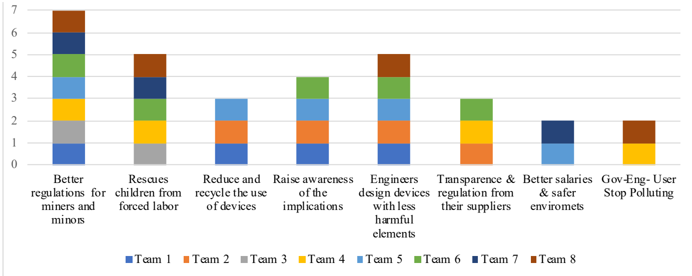

Fig. 4. Team's proposals to reduce adverse effects

4.3.1 Governmental involvement. Seven teams proposed actions, such as better regulations for miners and minors, and rescuing children from forced labor, that governments should address to reduce abuses created by cobalt extraction. For example, Team 1 recognized the need to improve regulations for both adult miners and children, while Team 3 included animated images of two women, a written message, and a voice message about their proposal for joint efforts between governments and international agencies to rescue children. The message read:

> *Regularly inspect workplaces, rescue children and adults from forced labor slavery, and reliably prosecute mine managers, owners, and buyers who violate the law and abuse child and adult workers. Major corporations, UN agencies, NGOs, and foreign government donors should collaborate with the Democratic Republic of Congo to make a reality.*

This excerpt shows that students focused on the complexity of solving the problem of irregular mining and the players that must be involved to provide solutions. They also indicated particular subjects in their descriptions (i.e., children, mine managers, owners, NGOs, etc.) to provide more specificity to the context of the problem. In addition, the students situated the problem in one particular geographical location – the Democratic Republic of Congo – to signify a specific locality of the issue.

4.3.2 Engineers' actions*.* Five teams included descriptions of how engineers can contribute to the reduction of problems created by the extraction of cobalt. Team 6 included superimposed text on an image of a machine to convey their message regarding their proposal for engineers to build machines that improve mining conditions for workers. Teams 1, 2, and 8 proposed that engineers improve the efficiency of devices or minerals to reduce adverse effects. And Team 5 included text and voice to describe their proposal for engineers to develop renewable action projects. The audio mentioned the following:

In order to solve this human rights crisis, engineers can work towards creating renewable cobalt programs, while governments can work to place regulations on the mining industry and increase pay of miners.

It is important to note from this excerpt that the students named the issue at hand as a "human rights crisis," and clearly identify engineers as subjects in the problem itself. Thus, the students communicated the critical role that engineers play in ameliorating the impacts of cobalt use and extraction.

4.3.3 Users' actions. Four teams mentioned actions that users should take to reduce the problems triggered by cobalt use. Teams 1, 2, and 5 proposed reducing the use of devices that use cobalt and recycling them after use. These same teams and Team 6 proposed increasing awareness of the excessive use of cobalt devices. For example, Team 2 included images of a phone that was turned off, accompanied by the caption "*Moving away from cobalt dependence.*" Team 5 included a video of a person recycling and included audio mentioning awareness of cellphone usage:

Users can be aware of the implications of buying common products like phones and work towards recycling these products.

In this case, students also identified users as actors in the cycle and proposed recycling and reducing the dependence on cobalt.

5 DISCUSSION

The results obtained from the data indicate that multimodalities were used not just to convey messages of the impacts of cobalt use and extraction, but also the ways in which students used modalities to help other engineering students make sense of the words (i.e., the research surrounding the use and extraction of cobalt) and the world around them (i.e., the detrimental impacts and social, environmental, and health ramifications) (Freire and Macedo 2005). The combinations of audio, text, video, and images provided the students with semiotic resources to organize their understanding of the problem, creating meaning for others, and helping the students themselves make meaning of it (Danielsson and Selander 2021). It is important to note that the multimodal artifacts created by the students also included their own personal touch to what they believed would better convey the message to the audience, and, in the process, they also utilized multimodal literacies to first get a better understanding of the concepts themselves. Thus, multimodal literacies have a great value for engineering education since they provide the tools for sense- and meaning-making.

Moreover, multimodal literacies also serve as an analytical tool to determine the ways in which engineering students are able to develop their own critical consciousness. Based on the data collected, it was observed that most of the students were able to overcome the stage of naïve transitivity (Freire 1997) because they reflected on their roles as users, as engineers, and as members of society when discussing the issues related to cobalt use and extraction. Of great importance is the fact that students try to engage in an "in-depth interpretation of the problems" (Freire

1997, 19) through an “interrogative, restless, and dialogical form” (Freire 1997, 19). The videos created by the students demonstrated a critical transitivity state (Freire 1997) that was concerned with in-depth analysis of the role of engineering.

It is important to mention that multimodal literacy also provides a way for engineering educators to engage students in a process that will help them develop their critical consciousness. Since the progression to critical consciousness is not automatic, the use of multimodal literacies are important to the “active, dialogical educational program concerned with social and political responsibility” (Freire 1997, 19) that is necessary to prepare socially responsible, critical, empathetic engineers. As the world of engineering continues to become more complex and solutions require not just mathematical and scientific prowess, it necessary to consider the role that multimodal literacies play in ensuring that engineering students problematize social, cultural, historical, environmental, political, and economic factors embedded in engineering work.

6 CONCLUSIONS

Multimodal literacy extends Freire’s emancipatory understanding of literacy to other disciplines, like engineering, and frames critical consciousness and literacy as steps toward collective action and social justice, rather than simply serving the interests of employers or capitalism. The analysis presented in this paper shows that the integration of multimodal literacies provides an effective strategy for engineering students to develop their own critical consciousness and awareness. The multimodal constructions created by the students integrated various interrelated modes of expression, which closely resemble engineering practices that rely on diverse semiotic representations to convey complex ideas (Wilson-Lopez et al, 2022). This paper suggests that multimodalities can facilitate understanding and communication of engineering concepts while preparing students for the natural complexity of engineering. This study also shows that critical pedagogical approaches (Freire 2003) allow students to investigate, identify, and express their own views on topics of interest, particularly pressing modern issues to reduce injustices through critical thinking. The themes on the videos also reflect a holistic view of the world where injustices and abuses are committed against children, miners, and embedded in globalized contexts. The findings of this study are specific to the chosen population and implementation. Future work can address these methods with other populations of students, allowing for a broader understanding of engineering students’ reflections.

7 ACKNOWLEDGEMENTS

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Enhancing Professional Skills Among Engineering Students by Interdisciplinary International Collaboration

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Conference Key Areas: *Engineering Skills and Competences, Innovative Teaching and Learning Methods*
Keywords: *international experience, interdisciplinary experiences, teamwork*

ABSTRACT

Providing necessary knowledge and skills for engineering students to become successful professionals is a tricky task. Besides disciplinary knowledge, e.g., communication skills, ability to work in teams, and international experience are often mentioned as important. Regarding internationalization, most engineering programs in Sweden rely on either student exchange or low-level internationalization-at-home, such as international literature and lecturers. This paper explores sustainable international experiences for students on their home turf provided through an international interdisciplinary collaboration where engineering students in Sweden and marketing students in Australia work together on a project. The setup simulates a consultancy firm with development and marketing offices in different countries that

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cooperate to launch an application for the Australian market. The paper is based on interviews and surveys with students and teachers participating in this, since 2017, ongoing project.
Findings reveal that students encountered several challenges that are hard to simulate in an ordinary university setting, e.g., language barriers, cultural differences, time differences, differences between disciplines, and varying work habits and values. The results also highlight opportunities such as learning from each other's perspectives and expertise, developing a more professional approach, presenting to people from other industry backgrounds, and gaining a better understanding of different cultures. The results show that the students gain professional experience that is of great value for their future profession. From a teacher's perspective, the paper discusses important issues when setting up an international inter-disciplinary collaboration, e.g., alignment of exercises, building a common ground, and the need for flexibility.

1 INTRODUCTION AND BACKGROUND

The advancement of technology has significantly impacted society, with engineering at the forefront of this development. The application of science, mathematics, economics, and social science has led to innovative engineering solutions that create value and intersect with scientific discoveries, technological development, and societal changes (Kumar 2018). Consequently, working as a professional engineer is demanding and requires diverse skills and knowledge. Some of the more generic skills that have been sought after by the industry for a long time are the abilities to collaborate and communicate across disciplines in a real-world context (Ertas et al. 2003; Mechefske et al. 2005). These skills are not unique to engineers but something that is important for all students. Hence, it is important for higher education to create curricula that develop skills in a relevant real-world context (Cardozo et al. 2002).
According to Fox (2022), "there is a need to help engineers develop skills for engaging with and working in international collaborative teams, particularly those useful for establishing and managing relationships across cultures and disciplines". Consequently, an important real-world context is the international perspective both within but also between disciplines. Internationalization can be defined as "the process of integrating an international, intercultural, or global dimension into the purpose, functions or delivery of postsecondary education" (Knight 2003). Furthermore, globalization has accelerated the need for international experiences in engineering education to prepare students for diverse work environments (Borri, Guberti, and Melsa 2007; Guillotin 2018).
This practice paper explores the concept of providing sustainable international experiences for students on their home turf through participating in an international interdisciplinary collaboration. Specifically, the paper reports on a collaborative project between a marketing course at Edith Cowan University (ECU) in Perth, Australia, and an engineering course at Umeå University (UmU) in Umeå, Sweden. Furthermore, learnings from a teacher's perspective of setting up and refining such a project are discussed. The setup of this project is based on a couple of goals: (1) Students should gain international experience without leaving their home country, (2) students should work in a simulated professional setting that is close to a real-life situation, (3) students should experience true inter-disciplinary collaboration, and (4), students should learn how to communicate their knowledge and discuss their work with those outside their discipline. The first three goals were set up at the very start

of the project in 2017 while the fourth goal has been added due to the importance of communication in collaborative situations and the reality that students seldomly get the opportunity to communicate their knowledge to non-disciplinary persons.

2 METHOD

The results in this practice paper are based on learnings from the teachers' designing and facilitating the collaboration between students. Students' views have been collected using entry and exit surveys during the courses where the students could write their view on their expectations on the collaboration (entry) and thoughts on collaborating (exit). Furthermore, semi-structured group interviews discussing the students' thoughts about the collaboration and their suggestions for improvements were performed to collect data for improving the collaboration. Consequently, this project has been conducted in an iterative process to gradually refine and change the collaboration to reach the goals of the project incorporating student feedback and academic and industry input. This project has currently finished seven iterations until fall 2022. Data has been collected during all these iterations; student quotes in this paper were taken from exit surveys during collaborations between 2019–2022.

3 CONSTRUCTING A PROFESSIONAL ENVIRONMENT

Project-based learning has gained popularity in engineering education as it offers a setting that can enhance both generic skills and discipline-specific skills among students (Mills and Treagust 2003). According to a review by Kokotsaki, Menzies, and Wiggins (2016), guiding students, having high quality group work, and basing assessment on peer evaluation are regarded as recommendations for successful project-based learning.

The collaboration was structured as a partnership between a marketing team in Australia and a software/UX development team in Sweden, located in different offices of a hypothetical digital agency. The project's broad problem definition allowed students to shape the project and reflected real-world scenarios where all necessary information for a project may not be readily available, like what students may face in their professional careers after graduation.

3.1 Development process

Working according to pre-defined processes is common within most areas. Within engineering or any discipline with a focus on development, there is often a product/service development process that is followed. This is common practice within the industry. Establishing common ground is important to understand both the process and the team's or individual's role in the process. In the case of Swedish engineering students collaborating with marketing students from Australia, design thinking can help bridge the gap between their different backgrounds and expertise. In this case, the general design thinking process was proposed as a basis to structure the students' work and give them a common ground to understand all steps of the process, from idea to market pitch, of a working prototype. Design thinking is a problem-solving methodology that focuses on understanding users and their needs to create innovative solutions that are both functional and appealing. It is a creative iterative process that is focused on understanding the users and the context.

The common design thinking process involves the following stages – *empathize*, *define*, *ideate*, *prototype*, *test*, and *launch* (Fig. 1). During the empathize phase, the focus is on understanding the users and their needs. This was done through e.g., research, interviews, and observation. In this case, the ECU marketing team conducted market research to understand the needs of potential customers and developed customer personas.

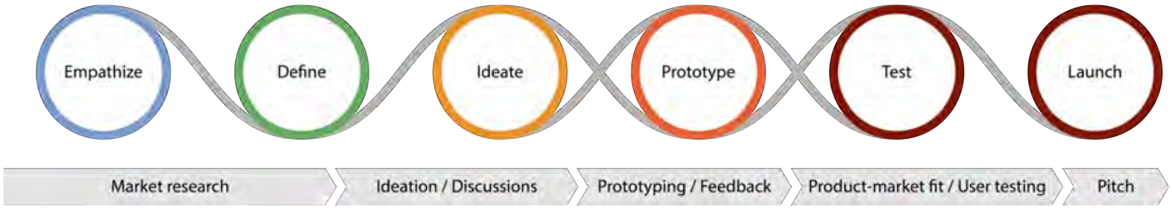

Fig. 1. A design thinking process was used to structure the work of the collaboration.

In the *define* phase, the problem is defined based on the insights gained from the empathize phase. This helps ensure that the problem which is addressed is the right one. The *ideate* phase involves brainstorming and generating a variety of functions and solutions. This is where the interdisciplinary collaboration shines because each group can contribute their unique perspective to the ideation process. The two teams identified problems and gaps in the market and discussed the practical feasibility of potential solutions. The ideation is executed through a teacher-facilitated session using a combination of applications for communication (Zoom) and collaborative whiteboard (Mural).

The *prototyping* phase involves creating a tangible representation of the solution and was divided into two milestones: a low-fidelity (LoFi) prototype and a high-fidelity (HiFi) prototype. These are sketches, wireframes, and digital prototypes, using e.g., Figma. The Swedish engineering students capitalize on their technical skills to create the prototype, while the marketing students provide feedback on product-market fit of the solution.

The *testing* phase involves evaluating the prototype with users to gather feedback and refine the solution. This stage is crucial to ensure that the solution meets the users' needs and is feasible to implement in practice. Depending on the amount of time at the students' disposal, this phase was more or less rigorously done. Part of this stage was done though product-market fit and involved presentations by the ECU students of their findings. Finally, and connected the *launch* phase of the development process, the marketing team created 90-second pitches for funding to take the product to market.

The design thinking phases were iterative and provided feedback to each other. The students were encouraged to stay in touch and share their progress. Consequently, using design thinking in collaborative interdisciplinary coursework is a powerful way to bring together different perspectives and expertise to create innovative solutions that address complex problems. By following the design thinking process, Swedish engineering students and Australian marketing students can work together in a professional setting to create solutions that are not only technologically feasible but also appeal to the target market.

3.2 Digital spaces for collaboration

Instead of using one of the common platforms for education, such as Canvas, Moodle, or Blackboard, the collaborative digital tools have been selected based on their ability to support the design process. The choice of digital tools in educational settings should, furthermore, support the pedagogical ideas of the setup. Hence, collaborative digital tools were introduced to increase interaction and collaboration between students both in real-time and asynchronously. Tools that are currently used during the collaboration are *Microsoft Teams*, *Zoom*, *Mural*, and *Padlet*.

Microsoft Teams has been used due to its extensive use in the industry. Teams was used for student team meetings and for keeping the team members updated on the progress by posting summaries of work, prototypes, and making comments. However, the asynchronous interaction through Teams proved to be ineffective as students often forgot to check notifications. Zoom was utilized for real-time collaboration when having full classes. However, it required setup by the teachers and was limited to scheduled weekly meetings. Mural was used for real-time collaboration during team meetings using pre-prepared templates and canvases, e.g., ideation, product-market fit, and elaborating on value propositions. Padlet was used to post summaries of work and sharing research report with other students. The students were generally positive about the use of these tools and believed they improved the collaborative learning experience. It is worth noting that the more widespread use of digital tools during in the emergency remote teaching situations during 2020 and 2021 has significantly increased the general knowledge among students of both disciplines regarding the use of digital tools.

4 LEARNINGS

It takes time and effort to set up a working structure of a collaborative project where both parties experience value from the collaboration and professional skills are developed. After running this project eight times and refining it iteratively, there are a couple of areas that have been identified as important to the process – *introduction*, *interactions*, *collaboration*, *digital tools*, and *timing*.

Introduction. Due to the large number of unknowns at the commencement of the collaboration, the introduction to the collaboration becomes very important. The students need to understand the holistic view and how they fit into the process. Even though one of the project's goals is to expose the students to the unknown, the misconceptions should be kept to a minimum. Hence, it is important that the students have a good understanding of the course's structure and the collaboration, so they can focus on the educational "unknowns". The continued improvement of the introduction process has created greater engagement and commitment from the students. In the pre-collaboration survey student express sentiments like these "I think I will get an experience in working with people that have other experiences and perspectives. I think that is a good way to prepare for the future since you will meet and work together with a lot of different people". Teachers are open about both strengths and opportunities for improvement with the setup and students are invited as co-creators of the collaboration. Furthermore, by working with a common development process, in this case the design thinking approach, it is easier to introduce the students to the project and make their roles and responsibilities clear. To further strengthen the understanding of the holistic project view, introductory lectures to the other students' discipline are important.

Interactions. Lecturer-facilitated and student-driven interactions are important to the process, and they have gradually increased over the years and the changes show that more teacher-driven interactions (e.g., scheduled joint class and team meetings) lead to more initiative on the students' side and more student-driven interactions take place (e.g., student scheduled real-time meetings). This is mainly due to more challenges surfacing with the increase in online discussions that in turn requires more meetings, online discussions, idea clarification and exchange. The students express this as: "We had to explain our process in an understandable way to students who are not as familiar with the area of our study. In the other way around, we did get some insights regarding their field of study” and “Understanding our differences and our similarities”.

Collaboration. Having a real collaboration that requires multiple touch points is important to create intrinsic motivation among students. A substantial portion of the courses are project work that two students need to perform in collaboration with each other ensures that all students actively participate in the international interdisciplinary experience. As one student expressed it: “Learning about different styles of communications, commitment to complete tasks”. Even though the engagement among the students increased when the collaboration became more integrated, it is still recommended that parts of the courses that are critical for the students to get grades are kept either separate (by e.g., exercises of laboratory work) or that there is a backup plan if for example a delivery is not made on time, or the quality of a delivery is questionable. However, examination-critical parts should remain largely independent to minimize uncertainties for students and give them control of their possibilities to finish the course on time even in case of problems with the collaboration. The students express positive feelings towards being “able to try and collaborate with teams from another countries” and that they “are learning collaboration skills different from the one’s you are used to (working with classmates)”.

Digital tools. Since all collaborations are online, digital tools become important. The tools used have been chosen based on usability and accessibility and how they support problem-solving and collaboration. This means that the toolbox has not been put together based on what the two Universities offer but rather what was needed. Furthermore, having in-depth introduction and demonstration of the tools used is necessary due to different experiences and backgrounds. Having a carefully selected set of digital tools increased the authenticity of the situation since online collaborative tools are commonly utilized in the workplace to interact with colleagues, crowd-source ideas, and engage users (de Marcos et al. 2016). This also increased the level of authenticity of the learning experience, the students expressed this as: “Thank you for proving us with the tools and knowledge which is helping me presently in my real time business/work”.

Timing. Working between academic systems creates problems such as having different starts of semester, study breaks, and examination periods. It is important to account for these problems beforehand. In this case the course in Australia starts in mid-February and runs to late May, while the Swedish course starts in mid-March and end early June. Hence, the timing of the final assignments is no problem, but the timing of the start is. The solution in this case was that the Swedish students participate in an introduction a month before their course starts. During the first month of the collaboration, the marketing students partake in marketing research to complete the empathize step in the design thinking process. Aligning exercises is challenging but important to create a collaboration that runs smoothly.

Even though many of the concepts discussed above can, and should, be planned, there is a strong need for flexibility from both parties. Having an agile approach to the collaboration with e.g., possibility to stretch deadlines and make slight changes to the schedule, decreases the effect of issues regarding communication and interaction among students as well as mistiming. This was done by regular updates using a WhatsApp group among the teachers to inform and make fast decisions behind the scenes.

5 MOTIVATED STUDENTS

Self-Determination Theory (SDT) (Deci and Ryan 1985) is a psychological theory that focuses on human motivation and personality development. According to SDT, human beings have three innate psychological needs that must be fulfilled for optimal growth and development – *autonomy*, *competence*, and *relatedness*. SDT suggests that when these basic needs are met, individuals are more likely to experience intrinsic motivation, meaning they engage in activities for their inherent enjoyment and personal satisfaction, rather than just for external rewards or pressure from others.

Gaining international experience in a simulated professional setting that is out of the ordinary for the students is of great value. It is, however, important to have motivated students since they are co-creators of the learning experience. The main success factors lie in the intrinsic motivation created during the collaboration based on autonomy, competence, and relatedness experienced by the students.

Autonomy refers to the need to be in control of one's own life and decisions and is achieved by giving the students control over their work in the project. The students are the "owners" of their projects, and they can decide on e.g., their own roles and have input in the project timeline. The teams' autonomy was often regarded as a frustration at the start of the collaboration since "Ideas kept flying" and "It was a bit awkward at times, since nobody took charge". However, comments such as "building friendship" and "diverse ideas" suggest that once this initial ice is broken, the autonomy helps the students to feel more invested in the projects and increases their motivation to work on them. Hence, the teachers' involvement is kept to a minimum once the collaboration has started and the interactions are working.

Competence refers to the need to feel capable and effective in one's actions and is achieved by providing a problem that is suitable for the students' current level of knowledge. This makes them feel that they have the necessary resources and training to perform their assigned tasks effectively. This also includes providing technical support for the engineering students to master their task. Feedback is provided both by teachers and by other students, mostly by peer feedforward, to make the students feel more confident in their abilities. The students express this as: "It was really good experience. I think it will help to boost our self to get better understanding of the subject" and "[The collaboration] showed what a workplace project can be like with different departments and working together to product the end result".

Relatedness refers to the need to feel connected to others and belonging in social groups and is supported by facilitating and encouraging communication and collaboration between the two groups. This is done through both video conferences and online discussions, allowing participants to connect and build relationships with each other. This strengthens the students' bonds both in-group and between groups and was expressed as: "It broaden my learning experience by collaborating with international students. It also exposed me to seeing product design and development takes shape" and "Nice to get another perspective on things, both cultural and because of different competences", and "overall was extremely helpful to develop our communication and teamwork skills".

By providing exercises, tasks, and an environment that promotes autonomy, competence, and relatedness, a higher level of intrinsic motivation among the participating students can be noted. This becomes evident both in the projects' results but, foremost, in how engaged the students are in the discussions and the project during the courses. It also strengthens the feeling for the students to get to

practice in a more realistic situation. This was expressed as: “Collaborating with international students in this unit gave me another opportunity to work with people from another country which in itself is eye-opening. In my experience collaboration is a skill that is valuable skill that is appreciated in the workplace”, “I think it has been a great experience to work with people with different study backgrounds. I think that it’s similar to what we will meet in the future in our work”, and “To be honest, I was a bit concerned at first given that it was two different area of study. However, as the collaboration started, I felt privileged to form part of this collaboration. Collaborating with students in Sweden has beneficial in many ways academically as well as what I will take with me to my future work-place”.
The frustrations experienced by students are in line with the goals of the learnings and show that the design of the collaboration is working. Students express this as frustrations regarding “communication and Technical issues”, “different views”, and “sometimes, we don’t understand them or their expertise, and vice versa”. Conversely one student considered “much of the benefits with working together was also sometimes the frustrations; that we have different knowledge and different will that we have to agree on or at least explain why something is better/more problematic. But the frustrations were also a good practice”.

6 CONCLUSIONS

To summarize, creating a real situation where students collaborate across disciplines, countries, and cultures enhances their learning and provides relevant professional skills for their future profession. Setting up a collaborative international and interdisciplinary project such as the one described in this paper is not easy and requires fine-tuning the details to create a valuable experience for the students and considerable commitment form the teaching staff. Fundamentally, in our experience, this includes communicating the project’s goal clearly to the students, inviting them as co-creators for the overall learning experience while still pushing them towards taking responsibility and project ownership, choosing the right digital tools, and following a meaningful design process for smooth project implementation. Moreover, teachers need to ensure that practical matters, such as issues regarding the timing of lecture periods, are addressed and deliverables aligned well between the courses. By incorporating exercises, assignments, and a supportive environment that fosters autonomy, competence, and connection, we can observe a significant increase in intrinsic motivation among the involved students. This is evident not only in the outcomes of their projects but, more importantly, in their active engagement during discussions throughout the courses. For the students the benefits are “practicing speaking English, working in your role (example as a developer or customer or marketers), take part of different knowledge and practicing on agreeing on different opinions and on enplaning why something is important/problematic based on your experience”.

6.1 Future work

Some of the improvements mentioned by students is concerning the balance when in time work is carried out between the two student cohorts. The main objective for future collaborations is to make both the engineering and marketing students to work more in parallel and create exercises where the marketing students can provide more of the information needed to align the developed application with the market needs. In the current collaboration the later changes on the prototype and the idea do not get researched towards the market. This would further strengthen the collaboration.

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Improving motivation and continuous assessment in engineering classrooms through Student Response Systems

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ABSTRACT

The use of Student Response Systems (SRS) is highly recommended to encourage the active and meaningful learning of students in each lecture. SRS promotes the motivation of students and improves the system of continuous assessment. One of the most popular applications designed for SRS is *Socrative* (Socrative n.d.). The use of *Socrative* gives real meaning to continuous assessment, since the teacher has an easily manageable record of the evolution of their students‘learning and will help the teacher to schedule both formative and summative assessment. The application allows the detection of topics that each student may not have understood and determines the percentage of the entire class with the same difficulty.

Beyond the use of *Socrative* as an evaluation instrument, sufficiently referenced, in this article we present different methodologies supported by SRS implemented in engineering studies at the University the Salamanca. The methodologies aim to promote autonomous work outside the classroom, and in face-to-face classes, to maintain the attention and lead the reasoning of the students to facilitate learning. The influence of the methodologies proposed by the authors on a series of indicators related to the motivation and commitment of the students to the subjects will be presented. To the best of our knowledge, most of the work on SRS have been applied to non-university educational levels and for assessment purposes and very few of them have applied SRS to undergraduate engineering studies. The novelty of this work lies in introducing new methodologies supported by SRS in university engineering studies.

1 INTRODUCTION

1.1 Student Response Systems

Among the difficulties of engineering studies, we can mention that the concepts are complex, that a solid mathematical and physical foundation is required, and that the student must dedicate a significant amount of time to individual study. The exercises that are proposed in technical subjects tend to be complex and tedious since data obtained from tables are required or these data must be obtained by previous calculation. Often, these exercises involve approximate solutions, simulations, and complex mathematical calculations. All of this makes it difficult for students to participate in the activities programmed by the teacher, whether as autonomous work or in the classroom. In addition to all these difficulties, it must be added that sometimes the groups are large (Caserta, Tomaiuolo, and Guido 2021, 46 [1]).

Researchers have agreed that active participation in classroom discussions improves student learning and that student-centered methods lead to an increase in satisfaction, engagement, and learning (Diaz, Hrastinski, and Norström 2023, 1 [2]). In this same sense, after several years as teachers, we realised that successful students are generally those who are more active throughout the course in the classroom, those who are capable of reasoning and raising doubts and difficulties related to the matter. These same successful students try to solve the exercises proposed by the teacher even if they do not solve them completely. From there, our teaching activity seeks to gradually introduce methodologies that increase students' commitment to study and class participation, while teaching them to reason and think.

A wide variety of works have been found in the literature in which Student Response Systems (SRS) are used to assess academic performance (Diaz, Hrastinski, and Norström 2023, 1 [2]; Squire 2023, 1 [3]; González-Campos, Castañeda, and Campos 2018, 667 [4]), but few are applied at the university level (González-Campos, Castañeda, and Campos 2018, 667 [4]; Bello and de Cerio 2017, 72 [5]; Bullón et al. 2018, 1818 [6]) and even fewer present their use in university engineering studies (Sun, and Lin 2022, 104430 [7]). Kocak (2022, 2771 [8]) reviewed 77 articles about the use of SRS but only 6 include the use of SRS in Engineering. Some experience carried out in Electronic Engineering (López-Quintero et al. 2016, 183 [9]; McLoone et al. 2013, 1 [10]), Mechanical Engineering (López, and Vinken 2013, 652 [11]); Biomedical Engineering (Tan 2017 [12]) and some study including several engineering (Barragués et al. 2011, 572 [13]; De Grez, and Valcke 2013, 1 [14]). In all of them, the main advantage of using SRS is that engagement is improved (Kocak 2022, 2771 [8]), improves classroom interaction and students' motivation with their study (Diaz, Hrastinski, and Norström 2023, 1 [2]; Kocak 2022, 2771 [8]).

Two systematic reviews investigating the use of SRS in health care studies (Grzeskowiak et al. 2015, 261 [15]) and in pharmacy studies (Hussain, and Wilby 2019, 1196 [16]) showed that the use of SRS improved participation, commitment, attention in class and even enjoyment according to the opinion of the students. In health care studies (Grzeskowiak et al. 2015, 261 [15]) better results were obtained when using SRS than when teaching took place through one-way lectures but did not improve compared to lectures with interactive questions.

One of the most popular apps designed to be used as an SRS is *Socrative* (*Socrative* n.d.). In its basic version it is a free distribution program that can be used from the computer or through mobile devices (http://www.socrative.com). Once a question or quiz is posed, the system captures student responses and instantly generates graphs or statistics from the responses. It supports short answers, multiple choice, or true/false questions. The use of Socrative in the classroom helps to carry out both a formative and summative evaluation since the teacher has an easily manageable record of the learning progress of their students (Santos, Merchán, and Prieto 2019, 111-134 [17] de Moffarts, and Combéfis 2020, 1 [18]). The global analysis of the results makes it possible to detect those aspects of the syllabus that each student has not understood, and even to determine the percentage of students who have the same difficulty.

According to Kocak, (2022, 2771 [8]), despite the great potential of the use of SRS, the best results are obtained by integrating educational technologies in the classroom with the appropriate pedagogical approaches, so more studies are needed on how to use SRS in the classroom that involve novel educational methods. With this idea in mind, and to encourage the active participation of the students, we present five activities supported by the use of Socrative that focus both on the orientation and correction of practical exercises, as well as on the guide of individual reasoning during the lectures of theoretical content. The proposal intends to motivate and to improve the performance of the students of the different engineering degrees of the University of Salamanca (Chemical Engineering, Mechanical Engineering and Materials Engineering). The activities have been tested for at least 4 academic years in the subjects of Thermodynamics, Chemical Kinetics and Electronics, with groups with a number of students between 40 and 140. To the knowledge of the authors, there is only one article for the use of SRS in chemical engineering with Kahoot! (Caserta, Tomaiuolo, and Guido 2021, 46 [1]), none in this specialty using *Socrative* and no studies considering different methodological uses of SRS in engineering studies and in different subjects.

A series of indicators related to class attendance, motivation and success rate have been defined. The results obtained in comparison with academic courses in which a traditional expository methodology was followed reflect that the implemented methodologies supported by the use of Socrative will improve the defined indicators.

2 METHODOLOGY

Five types of teaching methodologies combined with SRS have been implemented to create an active attitude during classes. The questionnaires that have been carried out are of two main types, those that aim to evaluate the work and study carried out by the student individually, and those that aim to guide the work and reasoning during the classroom activity.

In Engineering degrees there are usually abundant **laboratory sessions**. The degree of use of these practices depends largely on the fact that the students previously know the theoretical foundation of what is going to be studied and how the results should be treated. For the students to carry out the practices in the most autonomous way possible, the flipped classroom methodology is introduced. For this purpose, videos describing the practices: objectives, materials, realisation, etc. have been previously elaborated. Students must watch these videos before attending the laboratory. Subsequently, at the beginning of each practice session, they answer a questionnaire. In these questionnaires, they are asked about the practical work to be carried out that day. The usefulness of the questionnaires lies in the fact that they allow students to be aware of whether they have fully understood the practice or if, on the contrary, there are points that they must review before doing it. They can also be used as an additional element in grading students. An example of one of these questionnaires can be found at the link:

https://drive.google.com/file/d/1FVuJ2uA1mZ0-uT4SeIzsb_ZJoXDv_aW6/view?usp=share_link

Another of the applications that we have found to motivate students to work individually at home is based on the **correction of a previously requested model exercise**. The teacher selects a model exercise from the collection of exercises and its delivery is requested one week in advance. Before the student submits his solved exercise, the teacher launches the questionnaire about the problem, the students respond with their solved exercise in front of them, and in a maximum of 10 minutes the teacher has an Excel document with the grade of all the students, based on the solutions provided. The link shows an example of a questionnaire for the guided resolution of exercises in the classroom:

https://drive.google.com/file/d/1Hmv-5JR9w0rj1yG7Jy0aTDZE2v0eYrBw/view?usp=sharing.

Regarding the activities that are based on using the SRS in the classroom, it is worth noting **the guided resolution of exercises**. As already mentioned, the problems in these subjects are complex and lengthy. In the problem-solving seminars, teachers discuss step-by-step the procedure for solving the problem, but it is up to the students to work on it. To keep the students active at certain times, questions are sent through *Socrative* so that they can give partial solutions corresponding to some of the key sections. The link shows an example of a questionnaire for the guided resolution of exercises in the classroom: https://drive.google.com/file/d/108fVEpx6sgvCxUOdPCxnYFxswT-86cng/view?usp=share_link

The use of **SRS in expository sessions** is very useful as they help to dynamize the rhythm, so the student will be more focused on the development of the session. Although pre-designed questionnaires can be used in these sessions in the same way as in the examples previously mentioned, in this case it is particularly appropriate to use the Quick Answers option that *Socrative* offers. These questions are arising by the teacher during the lesson, which implies that, in the case of a multiple-choice question, the answers should be displayed on the black board so that students can choose between them appropriately. The use of this option changes the rhythm of the session and strongly involves the students, who go from being passive subjects to active ones, being also motivated by the competitive factor of seeing their answers projected on the blackboard.

One of the activities that is carried out with engineering students and that is proving to have great potential is the **classroom experiences** carried out by the teacher during a theoretical class session, with the collaboration of the students. They are carried out at the beginning of a content block, to awaken and clarify previous knowledge. For example, before beginning the study of Chemical Kinetics, the material is brought to the classroom to observe the effect of the initial concentration of a reagent and of the temperature on the reaction rate of decolorization of phenolphthalein in a basic medium. After discovery learning, it is essential to draw conclusions about the observed phenomenon. The SRS have proven to be very useful for obtaining information on the hypotheses and conclusions established by the students. Through SRS, the teacher asks about the effect that the experimental parameters have had on the rate of chemical transformation, and the statement of a general law is requested. The link shows an example of SRS to establish the behaviour observed during classroom experiences: https://drive.google.com/file/d/1-xxKtWy_OiIl7VMCm19Xy9SR_NYWPGn-/view?usp=sharing.

3 RESULTS: *STRENGTHS AND WEAKNESSES OF THE USE OF SRS IN ENGINEERING CLASSROOMS*

To evaluate the impact of the methodologies used in the different subjects, specific indicators are defined for each of them. The comparison with the indicators has been made between academic courses in which the described methods were and not were used, as indicated in Table 1 (results without SRS and with SRS). The selected indicators are: 1: Average marks in continuous evaluation, 2: Attendance at the classroom. 3. Attendance at the final exam. 4. Prior knowledge of laboratory work. 5. Success rate.

Table 1: *Results of indicators: Academic years with innovative methodologies and SRS (with SRS) and academic years without SRS (without SRS).*

<table>
<tr><th>Studies</th><th>Subject</th><th>Methodology</th><th>Indicator</th><th>without SRS</th><th>with SRS</th></tr>
<tr><td rowspan="3">Chemical Engineering</td><td rowspan="2">Physical Chemistry</td><td>Previously requested exercices</td><td>Average marks in continuous evaluation</td><td>7,2</td><td>5,3</td></tr>
<tr><td>Classroom experiences</td><td>Attendance at the classroom</td><td>74%</td><td>92%</td></tr>
<tr><td>Thermodynamics</td><td>Previously requested exercices</td><td>Average marks in continuous evaluation</td><td>7,5</td><td>5,4</td></tr>
</table>

		Classroom experiences	Attendance at the classroom	54%	80%
	Engineering Thermodynamics	Guided resolution of exercises	Attendance at the classroom	53%	74%
	Physics I	Laboratory Sessions	Prior knowledge of laboratory work	30%	75%
Materials and mechanical Engineering	Fundamentals of Electronics	Expository sessions	Attendance at the final exam	89%	100%
			Attendance at the classroom	70%	90%
			Success rate	70.8%	100%

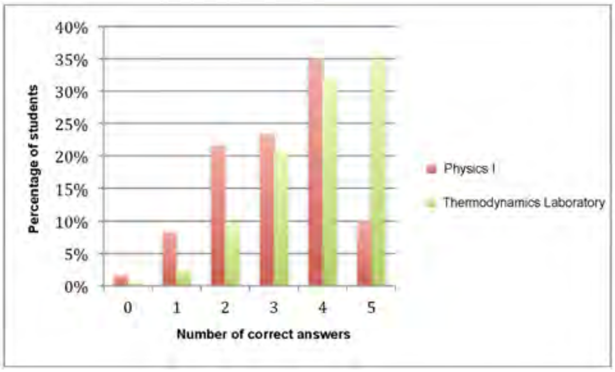

Fig. 1. Percentage of students with a certain number of correct answers, 0 (all wrong) to 5 (all right), for two different subjects.

Fig. 2. Classroom full before the call for a test with SRS.

Regarding the use of SRS before the **laboratory sessions**, one indicator is whether the students have acquired the necessary knowledge before attending the laboratory. Fig. 1 shows the percentage of students with a given number of correct answers, from 0 (all incorrect) to 5 (all correct), for two different subjects. Physics I is a subject of the first year of the Chemical Engineering Degree, while Thermodynamics Laboratory belongs to the second year of the Physics Degree. As can be seen, in both subjects the results are very good, with a percentage of students answering 4 or 5 questions correctly of 45% in Physics I and 65% in Laboratory Thermodynamics. It can be affirmed that 75% have previously worked at home on the scripts of the practical sessions or watched the videos, since they know that they are going to be surveyed with SRS. When this methodology was not used, only about 30% had done the previous preparation.

According to the bibliography consulted, the use of SRS has been aimed at assessment; SRS has not been used to check the understanding of the subject matter to be studied in the practical sessions in the laboratory. With this methodology the greater commitment of the students is remarkable, which results in a better performance of the laboratory work.

The use of SRS for “**correction of previously requested model exercise”**, results in increased student attendance in the classroom and more participatory correction of exercises. Considering the continuous assessment ratings indicator, in which the average of the 3-year ratings with and without SRS has been presented (from 2013 to 2016) without using SRS and with SRS (from 2020 to 2022) a decrease from 7.2 to 5.3 was observed. This result has been interpreted as a more faithful evaluation of the exercises the student has performed. When nothing is asked about the problem, the exercises are often copied among students and that is why the average mark is higher, and the attendance indicator increases (Table 1). Once more, we haven't found papers that describe the use of SRS to increment the individual work of students.

In the “**guided resolution of exercises”** methodology, one indicator is whether there is a difference between the number of students attending theory class and problem seminars. In Engineering Thermodynamics, it has been found that the number of students attending the problem seminars in which SRS are used, is approximately 20% higher than the number attending the lectures where SRS are not used (Fig. 2). The results match with those found by various authors, such as González-Campos, Castañeda, and Campos (2018, 667 [4]): the use of SRS reduces the number of absent students in the subject.

The use of the **Quick Answers option in expository sessions** in Electronics Fundamentals (on the degree in Materials Engineering and Mechanical Engineering) the attendance rate when using SRS has gone from 70% to 90%, approximately. On the other hand, the number of students who pass the subject has increased to 100% in the course where SRS have been used, compared to 70.8% in the previous course where SRS were not used. This result coincides with what is presented by López-Quintero et al. (2016, 183 [9]) which states that this methodology contributed to a better knowledge of theoretical concepts. In addition, the number of students who attend the exam increases from 89% to 100% in the course that we have used SRS. This increase means that students are more committed with the subject matter. Similar results have been obtained by Gonzalez-Campos et al (2018, 667 [4]) with a higher pass rate, better grades and higher attendance among students assessed with SRS compared to those assessed with the traditional system.

The use of **“classroom experiences”** has been valued very positively by students in satisfaction surveys carried out at the end of the subjects (90% of students value this activity with 9 out of 10). Even though the concepts introduced through the experiences are general, the perception of the students is that they better interpret the topic in which some experience is developed. The attendance indicator increases when some experience is previously announced. This match with what Gonzalez-Campos states: when using interactive tools to answer the proposed questions, all students showed a high degree of attentional focus, developing the psychological skill of attention-concentration (González-Campos, Castañeda, and Campos 2018, 667 [4]). However, Grzeskowiak (2015, 261 [15]) indicates that the use of SRS does not improve results when compared to lectures with interactive questions.

It should also be noted that, in general, attendance at lessons or seminars in which an SRS is announced has increased (Fig. 2). At the laboratory the attendance is mandatory, whereby the attendance has not been evaluated.

After several years using SRS with different teaching methodologies in engineering courses, we can summarise its main strengths and weaknesses in Table 2.

Table 2: *Weaknesses and strengths of the use of immediate response systems in the classroom.*

Strengths of SRS	Weaknesses of SRS
● Very intuitive. ● Easy to learn how to use. ● Daily and personalized monitoring of students. ● Detects less understood concepts (formative evaluation). ● Provides a record of the learning evolution of each student (summative evaluation). ● Increases student motivation for the subject and attention during classes. ● Encourages the participation of insecure students. ● Enables participation from outside the classroom (incompatibility of students). ● Increase attendance if SRS sessions are scheduled.	● Answers are inevitably directed. ● Discussion, analysis, and reflection are limited. ● It does not allow to improve the written expression. ● Motivation is fostered only by rewards. ● Enables participation from outside the classroom (absence of new students).

4 SUMMARY AND ACKNOWLEDGMENTS

Different activities and methodologies supported by SRS that have been used in several Engineering studies at the University of Salamanca are presented: test prior to the laboratory sessions, correction of previously requested model exercises, in the guided resolution of exercises, in expository sessions, after a classroom experience.

In general, attendance at lessons or seminars in which there are pre-announced SRSs has increased. In the practical sessions, the use of SRS increases the number of students who have worked the practice scripts before entering the laboratory, improving performance. In type-correction exercises requested as individual work, the evaluation is more reliable, and the grades are lowered. All the indicators analysed lead us to think that these methodologies reduce dropout and facilitate student success by increasing their commitment to study.

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Use of the triple-bottom line framework to examine the design tendencies of first year engineering students

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ABSTRACT

Engineering design often requires the examination of multiple different factors and a design selection based on compromise between these factors. An engineer's preexisting values and experiences can influence design decisions. Therefore, knowing and understanding these design tendencies can prove valuable in guiding engineering students with their future design selections. The purpose of the project is to examine the design tendencies of first year engineering students using an interactive web-based virtual reality (VR) module focused on the triple-bottom line framework. The triple bottom line sustainability framework measures design in three key areas: people, profit and planet. The course for which the interactive module has

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been developed is a first-year engineering course called Chemistry of Natural and Engineered Systems. The activity is based around the chemical production of 6-aminopenicllianic acid through hydrolysis of Penicillin-G. This paper presents an explanation of the interactive web-based VR module, explores student design tendencies before an optimization problem, evaluates their design selections while completing the optimization problem and analyzes student reflections. Determining students design tendencies before the VR activity will help the teaching team gain insight into student thinking process about engineering design and determine the extent of variability of first year student design tendencies. We also envision this project as the first step of a longitudinal project to investigate the influence of undergraduate engineering education on student design tendencies.

1 INTRODUCTION

Engineering design can be defined as an iterative, systematic process for solving problems that involves creativity, experience, and accumulated disciplinary knowledge (National Assessment Governing Board, n.d.). For most undergraduate engineering programs, the design process and the elements of complex problem solving along with "engineering science" are introduced to students in the first and second year of their programs and then applied in senior undergraduate courses (Dym et al., 2005). This is based on the notion that students require discipline specific knowledge and experience before they can appropriately apply the design process. A delay in introducing discipline specific design activities can be seen as an obstacle but it also presents an opportunity to study pre-existing design tendencies. Therefore, the first-year undergraduate engineering would be an ideal time to examine student design tendencies given we, as educators, have not provided them with design guidance and instruction that might influence their propensities.

Engineering design also requires knowledge beyond technical knowledge such as sustainability. Sustainability has become an integral part of engineering education (Abd-Elwahed & Al-Bahi 2021), given the United Nations 2030 agenda for sustainable development goals (Tseng et al., 2020). Watson et al., (2013) has distinguished two types of sustainability integration into the curriculum: vertical and horizontal. Adding a specifica sustainability course to the curriculum woud be an example of vertical integration, while horizontal integration involves including sustainability topics across several courses. Active learning pedagogies, including problem based learning, role plays and case studies has been identified as effective approaches to teach sustainability (Segalàs et al., 2010). For example, in a study by Von Blottnitz et al., (2015) a new first-year core course was designed for chemical engineering focusing on sustainable development. A focus of the course is on 'natural foundations' which introduces nature not just as the source of raw materials but also as 'mentors and models'. The course involves both theory delivered through lectures as well as group projects and writing assignments.

A critisim associated with integrating sustainability in the curriculum is the exclusion of the social and economic dimensions by focusing only on environmental dimensions (Watson et al., 2013). To address all those dimensions, the triple bottom line framework first proposed by Elkington (1997) could be used which attempts to find compromise and sustainability between planet, people and profit. Triple bottom line was redefined by Carter and Rogers (2008) as follows: “sustainability should hold economic performance, the natural environment and society at a broader level, and the intersection of social, environmental and economic activities can help organizations become engaged in activities that not only positively affect the natural environment and society but that also result in long-term economic benefits and competitive advantage for the firms.”

The purpose of the project is to examine the design tendencies of first year engineering students using an interactive module based on the triple-bottom line sustainability framework. The triple bottom line framework was selected for this study given its ease of understanding/applying and the strong emphasis on sustainability in engineering and engineering education. The aim is to help students become aware of their design tendencies and complete one of their first design experiences in the form of an optimization scenario, while introducing the concept of sustainability. The interactive module includes a desktop Virtual Reality (VR) chemical plant where students can change variables for the chemical production of a compound. The use of VR provides an immersive and interactive learning environment for students and provides a means to easily change the variables and observe the effect on outcomes of the reaction. In this study we defined design tendencies as the degree to which students focus on people, or planet or profit in an engineering design. The VR was used as a tool to embed sustainability in the course and hence not the focus of the study.

2 METHODOLOGY

2.1 Course setting

The course for which the interactive module has been developed is a first-year engineering course called Chemistry of Natural and Engineered Systems at Queen’s University. The course introduces thermodynamics, chemical process dynamics, and electrochemistry in the context of sustainable engineering design. The course is delivered face-to-face through lectures and tutorials to over 700 students.

2.2 Triple bottom line interactive module: description

The triple bottom line interactive module is an extension and complementary to an assignment completed earlier in the semester. The assignment is based around the chemical production of 6-aminopenicllianic acid (6-APA) through hydrolysis of Penicillin-G (Pen-G) shown in Figure 1. The students are asked to generate an expression for the rate of Pen-G hydrolysis as a function or reagent concentrations. Next, students are asked to use their rate expression to predict the time in hours that is required to achieve 50%, 95%, and 99.9% conversion of Pen-G to 6-APA. The aim of this assignment was to provide students with some background knowledge about the reaction and the variables affecting the reaction outcomes.

The assignment is followed by an interactive module hosted on Articulate RISE 360, and includes explanation of relevant concepts, a web-based Virtual Reality (VR) exercise for the chemical process of 6-APA and reflection questions. More specifically, the module begins with a description of the exercises and learning objectives, an overview of the chemical process including the reaction, and process block flow. Students are then presented with a description of independent variables for the reaction such as pH, temperature and catalysts which can affect the outcome variables such as rate constant, mass of product and energy consumption, with the latter contributing to people, planet, profit variables. The module provides the students with a review of the concepts used for earlier calculations in the completed assignment. A process well known to the students was selected so that they were not required to learn new material and could focus on the optimization problem.

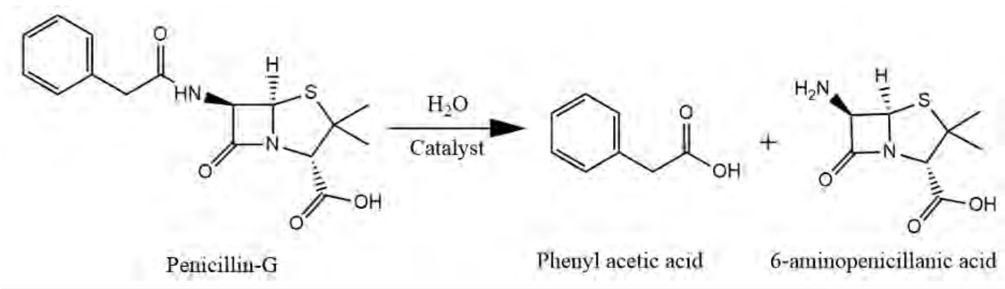

Fig. 1. Chemical reaction for production of 6-amino-penicillianic acid

A short description of the triple bottom line framework is then provided, followed by variables used to calculate a sustainability index in the VR. Examples of the variables include process hazard index (people variable), equivalance CO_2 emissions and volume of aquoues waste (planet variable), and cost of reagents, heating and utilities (profit variables). Students then complete a survey where they are asked to examine their design tendencies by allocating points to people, planet and profit, and providing a brief explanation for their rationale. This is referred to as the pre-VR survey throughout the paper.

Next, students are instructed to download the VR application on their desktop. Once in the VR environment, they have the opportunity to first tour the chemical plant (Figure 2), and are guided to find specific unit operations inside the plant which are relevant to the production of 6-APA. Students can then enter the control room where they can examine the structure of the product (Figure 2).

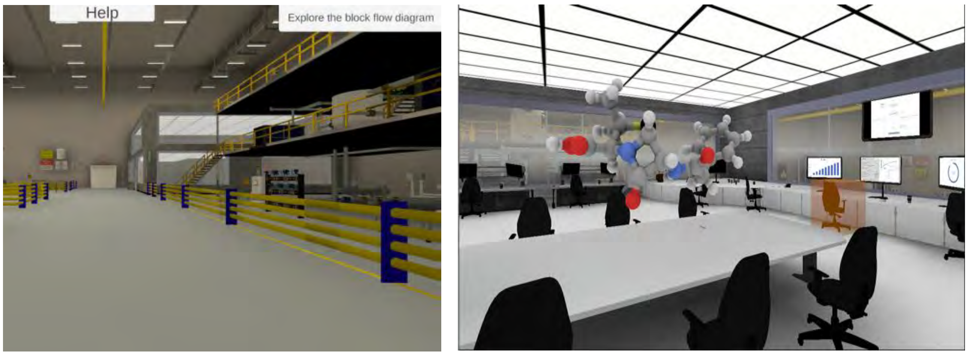

Fig. 2. Tour of chemical plant (left) and chemical plant control room (right) within the virtual reality environment

Next, students are asked to enter the variables obtained in their earlier assignment to understand how they affect the triple bottom line sustainability score. For this module, the semi-quantitative methodology developed by Penn & Fields (2017) was adapted which rates a design for each of the 3Ps using a radar chart as below (Figure 3). Each of the 3Ps is given a value from 0 to 100 which forms a triangle representing the relative values of each P. Any imbalance among the 3Ps will be apparent in the radar chart.

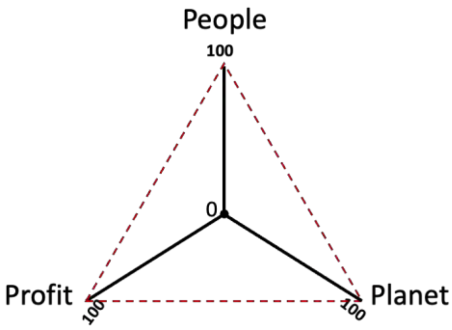

Fig. 3. Triple bottom line radar chart. Adopted from Penn & Fields (2017)

A sustainability index score can then be calculated as follows (Penn & Fields, 2017):

SI = [sum of 3Ps – (maximum of 3Ps – minimum of 3Ps)],

- 0: completely unsustainable
- 100: Moderately unsustainable
- 200: Moderately sustainable
- 300: Fully sustainable

Students are then instructed to optimize the chemical production of 6-aminopenicillianic acid based on their own design tendencies. They can observe the effect of changing each variable on people, planet, profit and the overall sustainability index (Figure 4). The module ends by asking students to write a short reflection for their rationale in choosing those variables, and two Likert scale questions about their design tendencies and the future use of this information.

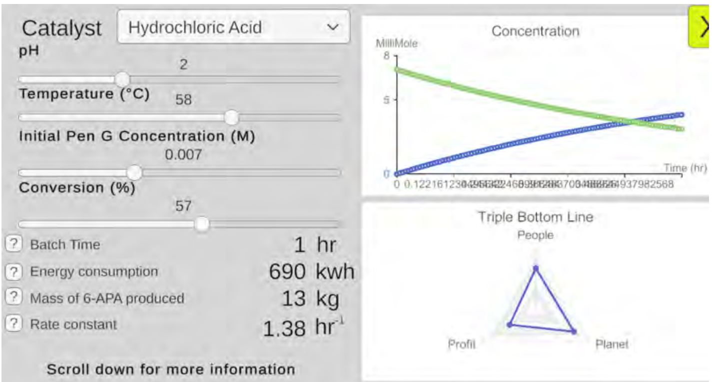

Fig. 4. VR control room triple bottom line display and user interface

3 RESULTS

At the beginning of the RISE module students were presented with a consent form to use their data for research. 356 students provided consent. 292 students filled out both the pre-VR survey and the VR exercise. In the pre-VR survey, students were asked to allocate 100 points to people, planet and profit. 13 responses were removed because the scores students provided did not add to 100.Table 1 shows the average score for each of these variables: People and planet almost scored the same, with profit having the lowest score. In the VR exercise, students were asked to optimize the people, planet, profit variables for the chemical production of 6-APA based on their own design tendencies. Interestingly, profit had the highest score with planet having the lowest score (Table 1). The last column shows the change in average scores and is calculated by subtracting pre-survey scores from the VR exercise scores. As shown, profit has the largest positive change given it had the highest score in VR. This indicates that students might have a pre-existing tendency to consider profit as not as important as other variables; however, when applying the triple bottom line framework to this optimaization problem profit played a larger role in sustainability.

Table 1. Students' triple-bottom line scores for pre-VR survey and VR optimization exercise(N=279)

	PreVR Survey		VR Exercise		Difference (VR - preVR survey)
	M	SD	M	SD	
People	37.46	6.44	33.66	3.06	-3.80
Planet	35.97	6.62	32.36	1.61	-3.61
Proft	26.96	8.01	35.36	4.03	+8.40

The aim was for students to choose the VR variables based on their own design tendencies. However, the open-ended responses related to student justification indicate that students might not have relied completely on their own tendencies. Most students commented that that they aimed for a balanced radar chart and a high sustainability index score. The radar chart visualization (Figure 4) might have affected student decisions and guided them to create an equilateral triangle. Thus, the pre-VR survey might be more indicative of students' design tendencies.

Students were also asked to rate two Likert scale questions on the effect of the module in helping them understand their design tendencies and the use of their design tendencies to inform their future design activities. Table 2 shows the response percentages with over 70% of students agreeing to both statements (N=186). While acknowledging the limitations of this survey given the limited number of questions asked, it provided encouraging results for follow-up studies to develop a more robust survey instrument and/or conduct longitudinal studies to explore student design tendencies as they move through the undergraduate engineering education.

Table 2. Students' responses to two Likert scale survey statements (N=186)

	Strongly agree/Agree	Neutral	Strongly disagree/disagree
The triple bottom line module (the background information, reflection questions, VR design activity) provided me with insight into my design tendencies.	71%	24%	5%
I will use the knowledge regarding my design tendencies to inform my future design activities	73%	26%	2%

Students were also asked to explain their answer for the use of the design tendencies in their future design. The majority of students indicated that they would use the triple bottom line framework and would consider its variables in their design to aim for a sustainable design. This was a more superficial response focused on the VR experience whereas the instructional team was interested in a deeper reflection. This could have been because of the statement wording or that it might be difficult for students to comment on their future deign tendencies given that they don't have extensive design experience. However, a few interesting themes were observed. One was awareness of bias; a number of students indicated that they will be more aware of their bias in their future design activities . For example, one student mentioned:

"*Knowing how I consider design, I can move forward with design activities with my own bias in mind.*"

While another student commented:

"*My future design choices will be led by a more thorough and thoughtful approach to the benefits and disadvantages of design decisions. I feel as though I better* *understand my own way of thinking, and I can use this knowledge to prevent personal bias from interfering in decisions pertaining to engineering."*

Bias has been observed in engineering design industry and specifically is associated in idea selection step (Onarheim and Christensen 2012; Toh et al. 2015), and this understanding and evaluating personal bias is important for engineering students. One such bias is the ownership bias which is preferences for one's own ideas compared to other people's ideas (Toh et al. 2015). In a study by Cooper et al. (2002) it was found that design companies face challengues during idea screening and selection because of designers' bias, which could impact the final design and success of design (Hambali et al. 2009). Though different than ownership bias, the module appeared to have helped students become aware of their bias with respect to the triple bottom line framework.

Some students also indicated that in the future they will be more aware that all decisions and factors will have an impact and outcome. For example:

"*I was shown how small tweaks in a project parameter can have a great impact on the environment, people and also the profit of the project."*

Other interesting responses included consideration of "*multiple difference methods prior to creating a design," "to always consider the ethical concerns," "to orient my design towards the betterment of society,"* and *"I now know that when making a design it does not always happen correctly on the first try. "*

4 CONCLUSION AND FUTURE WORK

An interactive module based on triple bottom line was developed and implemented in a first-year undergraduate engineering course to examine student design tendencies. The module complemented an earlier assignment in the course on chemical kinetics. The interactive modules included a desktop VR environment which provided a simulated environment to easily adjust variables to optimize a chemical reaction based on the triple bottom line framework. Results indicated differences in student initial design tendencies and in the optimization scenario. Students also indicated the module helped them in understanding their design tendencies and that they will use this knowledge in the future.

Our future plans include using the themes from the student open-responses and literature to create an instrument on design tendencies to study and examine it in a more systematic way. Investigating student optimization responses with and without visualizing the radar chart and using qualitative data such as think-aloud or focus groups will also help us to design a more effective module. A longitudinal study tracking student design tendencies as they move through the 4-year undergraduate engineering education would help us to examine the effect of the program on student design tendencies.

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Challenge-Based Learning and Constructive Alignment: A Challenge for Information Systems' Educators

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ABSTRACT

Challenge-Based Learning (CBL) is an emerging approach to the design of education activities known for its benefits in fostering student engagement and, consequently, positively affecting their learning outcomes. For the educator, the '*challenge in the challenge*' is to guarantee that the CBL-based education design follows certain regulations, like ensuring proper curriculum coverage with Constructive Alignment. This challenge becomes particularly difficult to address in the field of Information Systems, within Computer Science, where multiple practices can be followed to solve the same problem. This is even more challenging when CBL is applied at course-level, where the curriculum of the course focuses on a subset of those practices. This paper targets two central questions for the educators willing to apply CBL while complying with Constructive Alignment in their course design: (1) How to ensure that the results based on solutions designed to address student-defined challenges are successfully aligned to the course's intended learning outcomes? (2) How to use these results as evidence of learning and as an assessment component? We discuss our experience and lessons learned applying CBL for the redesign and execution of the Smart Industry Systems course of the University of Twente, while ensuring proper curriculum coverage and compliance with Constructive Alignment.

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1 INTRODUCTION

The University of Twente's (UT) mission is to empower society with sustainable solutions in order to put people first (UT 2023). UT seeks to achieve excellence in connecting people and technology by fusing technical and social sciences in various domains: enhancing health care through personalized technologies, developing intelligent manufacturing systems, reshaping our world with smart materials, engineering our digital society, and engineering for a resilient world. Consequently, UT is concerned with educating students effectively through courses that equip them to face challenges in various fields.

The Smart Industry Systems (SIS) master course is offered in the Business Information Technology Master (M-BIT) programme, as a mandatory part of the learning path for all students. The course is also offered as elective to other programmes, and it is particularly popular amongst Computer Science students. SIS has been offered for three years now, and students have ranked it as the best course in their programme in various categories, e.g., course content relevant to the educational program, clear and related learning goals. To further connect people and technology, align with UT's mission and vision, and provide students with the opportunity to participate in and control their learning, in 2022 we decided to apply the Challenge-Based Learning (CBL) approach in the SIS course.

CBL is an educational framework designed to support students (learners) to learn by means of an iterative life cycle of three phases (Nichols and Cator 2008)(Nichols et al. 2016). CBL drives learners through real-life challenges, and a multidisciplinary team supports the learners, including the challenge provider, lecturers, student assistants and a CBL mentor. Skills developed with CBL can increase the impact that learners have on society during and after their studies (Johnson et al. 2009). The CBL life-cycle covers three phases: (1) Engage, where learners move from an abstract big idea to a concrete and actionable challenge; (2) Investigate, where learners conduct research for actionable and sustainable solutions; and (3) Act, where evidence-based solutions are developed and the results are evaluated.

Studies have shown that students in higher education settings working within the CBL framework can boost their skills (e.g., leadership, autonomy, and critical thinking), maximizing their learning experience (Johnson et al. 2009), (Doulougeri et al. 2022b), (Martin, Rivale, and Diller 2007). Recent literature has shown that CBL can be particularly efficient for the topic of smart applications, e.g., in the case of 'smart campus' challenges (Zaballos et al. 2020). Therefore, the SIS was a suitable candidate for applying CBL, so students could benefit from this framework. This study discusses the effectiveness of implementing the CBL framework in the SIS course.

However, applying CBL in a course based on Constructive Alignment (CA) is challenging for the educator to guarantee certain educational constraints, such as proper curriculum coverage. This challenge is even harder in CS courses, where multiple practices can solve the same problem. This paper targets two central questions for the educators willing to apply CBL while complying with Constructive

Alignment in their CS course design:

- RQ1. How to avoid misalignment between the course's intended learning outcomes (goals) and the learning opportunities generated by student-defined challenges (teaching and learning materials)?
- RQ2. How to ensure that student-developed solutions provide evidence of learning (assessment) aligned with the course's intended learning outcomes (goals)?

This paper reports on a case study in which we address these questions and discuss the results, which are based on a comparison between the editions of the SIS course with and without applying CBL. The remainder of this paper is organized as follows. Section 2 presents the case study. Section 3 presents our findings and discusses them. Section 4 concludes and suggests topics for future research.

2 CASE STUDY: APPLYING CBL IN THE SMART INDUSTRY SYSTEMS COURSE

In this case study we compared the original SIS course given in 2021 as a "pure" project-based course, without applying CBL, with the 2022 edition in which CBL was applied. One of the motivators to use the SIS course is that recent research has demonstrated that CBL is particularly useful for the study of smart applications engineering, and entrepreneurship (Doulougeri et al. 2022b), (Doulougeri et al. 2022a), (Couch and Towne 2018), (Colombelli et al. 2022), (Gaskins et al. 2015).

2.1 Original Smart Industry Systems Master Course

In 2020, M-BIT and M-TCS master's students took the first project-based SIS course. The SIS course addresses business interoperability concerns in an integrated network of automation devices, services, and enterprise systems in the industry ecosystem, covering the full production process and multiple enterprise sectors. Real-world interoperability project assignments make the course multidisciplinary. In SIS' original course design, students spent half the time on lectures and related assignments and the other half on developing one of the predefined projects available. The projects' descriptions include the research context and some problems/research questions to be investigated, similar to what is described in (Bacon, Stewart, and Silver 1999) and (Bacon 2005). The bottom line here is that students worked on predefined research questions on projects drawn based on real-world projects (specifically inspired by one of the region's companies). Although the connection with reality is present, it's unclear how much of this connection is perceived by the students. Additionally, since the course lasts only ten weeks, we saw the predefinition of problems/tasks as an efficiency measure - since it helped avoid students using time for the precise definition of the investigation to be conducted.

2.2 The adaptation to CBL: working with ill-defined problems

Since 2021, the BIT programme management has motivated lecturers to offer students ”ill-defined” problems. The goal is to give students the opportunity of developing critical thinking and continuously develop the ’researcher approach’. Therefore, the ’efficiency measure’ we took in the previous design became inconvenient for the achievement of these new intended learning outcomes. Additionally, since CBL is inherently designed to guide students in the investigation of ill-defined problems (they usually define the challenge themselves), and also because CBL is known for increasing students’ engagement, we decided to update the SIS course from a typical PBL (Project-Based Learning) approach to a ’feasible’ CBL approach.

Our ’feasible’ CBL approach requires the entire learning cycle to take less than ten weeks. Leveraging on the fact CBL is a framework and not a method (Nichols et al. 2016), and its application has been continuously adapted by the founders themselves (Binder et al. 2017), we adapted our CBL approach to give students a written description of the research context, which is always the case of a local company. Since the issue is unclear, students were given multiple weekly times to discuss with company officials. These weekly time-sensitive exercises and milestones were meant to assist students stay on schedule. We predefined the ”Big Idea” and provided a context description for students to gather throughout the ”domain investigation phase” of CBL. Therefore, students had to investigate which challenges are more relevant to the companies and discuss (within the group) which ones engage them the most. Some differences from the original design are: (a) the connection with companies is now explicit, including weekly contact hours with company representatives, (b) the problems are no longer predefined, and (c) students use the CBL structured questioning schema to guide their investigation process (learning ”how to investigate,” i.e., the researcher approach). Additionally, to prevent disconnection of the chosen challenge with the ’teaching and learning materials’ and ’assessment’, each case had a set of constraints to ensure the chosen challenge (learning material) and the chosen solution (assessment material) are clearly connected to the course’s intended learning outcomes. Therefore, our approach differential is to steer students’ learning experience more than the classical CBL application. Consequently, in our approach, students have less freedom to choose their challenges and the solution to be developed.

When adapting the PBL to a CBL approach, the evaluation becomes more challenging. This is because students may define/identify challenges beyond the course material, which might result in having challenges not covering the course’s intended learning objectives (ILOs) (Nichols and Cator 2008), (Martin, Rivale, and Diller 2007), (Johnson et al. 2009). With CBL, students elaborate Guiding Questions (GQ) that help them learn by ’inquiry’. At this point, we offered students a team of CBL Mentors (lecturers) to help them in their journey. The mentors helped students in assessing whether their set of GQs covered all the knowledge they had to acquire and also whether the knowledge to be acquired is connected to the ILOs.

2.3 CBL Mentors: additional contact-hours for increased educational support

The new pedagogical design included the addition of lecturers (called 'CBL mentors') to support students in the definition of the challenge (engage phase) and the learning activities (investigation phase). This measure helped to ensure the Constructive Alignment. Furthermore, the mentors worked as a bridge, connecting students to challenge providers and moderating this relationship.

3 RESULT ANALYSIS & DISCUSSION

The analysis of the results pointed to two directions: the need of mentors and the need of adapting the CBL phases to assure Constructive Alignment. Here we also describe the perceived quality of the course, and discuss the research findings.

3.1 The need for mentors

Although we provided students with a research context description and a structured schedule of contact-hours with companies representatives, we found it still relevant the risk of disconnection between learning materials (represented by the CBL Investigate Phase and its Guiding Questions), assessment (The solution developed and its report), and the courses ILOs. The CBL mentors played a key role in mitigating this risk of breaking the constructive alignment.

The contribution of the mentors go beyond steering the learning experience. Through their interaction with students, Guiding Questions were rewritten, Challenges were redefined, and students were continuously prompted about their responsibility in defining their own learning experience. More than simply steering the learning experience, the mentors shared 'tacit knowledge' on how to systematically approach the investigation of a given problem/challenge. Although difficult to measure, we can't ignore the importance of the mentors in helping students develop their 'researcher approach'. Therefore, beyond 'feasibility', the mentors contribution also had an impact on what and how students learned during the course. Finally, although the 'cost' of this added measure may seem relevant by some, it's important to consider the support for tacit knowledge transfer brought by such a measure.

3.2 The Need for adapting CBL phases

The SIS-CBL edition (2022) had 16 groups of four students each. The CBL mentors were available from weeks 5-9, and, since they were not specialists in all topics (and challenges), their responsibilities were mainly related to the students' learning experiences within the CBL framework. Table 1 presents a summary of the traditional and CBL milestones expected to be observed from each participant group of the SIS course, in accordance with the CBL phases (engage, investigate, and act).

In the engaging phase, CBL mentors prioritized group involvement and participant excitement for the challenge. Given the students' enthusiasm in solving the challenge

Table 1. CBL phases and milestones throughout mentoring and project development.

CBL Phases	Expected and observable milestones
Engaging	**(1) Classical CBL:** (I) Select an application case, (II) Brainstorm essential questions and formulate the main problem to be further investigated (Select a ”topic”), and (III) Pitch idea to the case owner and receive approval to investigate, develop, and implement their ideas. **(2) Adapted CBL approach:** (I) Formulate essential questions, which could not be closed questions, (II) Ensure that all participants within each group are involved, engaged, and motivated with the selected main problem to be investigated, and (III) Ensure that the potential selected challenge is within the scope of the SIS course and is something that can be tackled within the course's timeline.
Investigating	**(1) Classical CBL:** (I) Select formal materials (e.g., books and research papers) to refer to the proposed solutions, and (II) Whenever possible, identify comparable work and establish a benchmark for the selected methods. **(2) Adapted CBL approach:** (I) Provide a preliminary solution to the challenge, (II) Frame the challenge as an action that will lead to the next CBL-phase rather than an open (or closed) question, and (III) Reflect on the ongoing work.
Acting	**(1) Classical CBL:** (I) Implement the suggested solution, observe, and (II) Present conclusive results in a written report and oral presentation **(2) Adapted CBL approach:** (I) Ensure that the challenge selection and the main methods and experiments used to address this challenge are highlighted in the final report and presentation. (II) Ensure that students and case owners understand the contribution and relevance of the proposed solutions, particularly when comparing the final solution with the preliminary solution provided in the previous CBL-phase (investigating), and (III) Reflect on the tasks performed within all CBL framework steps.

they highlighted, the CBL mentors helped them refine their important questions during brainstorming. This was important because most of the students' inquiries were closed or outside their goals. The CBL mentors gave case owners a brief report with comments after each group meeting to help them decide whether to accept a challenge and address any potential issues with group formation or team member participation. After the engage phase, each group had picked a clear and preferred challenge with crucial questions related to the course curriculum.

During the investigation phase, CBL mentors ensured that (1) the groups' challenge was accepted by the case owners; (2) they had an initial idea of how to approach the challenge (preliminary answers); and (3) students knew where to look for potential elements to get to solutions (e.g., tutorials, books, articles). Thus, in the investigation phase, assisted by CBL mentors, students merged the essential questions and related them to the main challenge, recommending materials (or lecturers) to address these questions, and analyzing with group members the feasibility of their solutions to their challenges, considering project milestones (deadlines). After each meeting, case owners and lecturers received student reports.

In the action phase, CBL mentors helped students choose a solution design orientation, implement chosen approaches, and evaluate their results. Students were in closer contact with the case owners, who were experts on each industry problem, while the CBL mentors guided them through the challenge management steps and provided constant feedback on how to incorporate the findings into the graded project deliverables (presentation and report). Case owners and instructors received a summary of the CBL session. The CBL mentors were present for project presentations and saw that most groups followed the CBL storyline: presenting the challenge, how they identified their interests and problems, and the proposed solution.

3.3 Students' satisfaction and perceived quality

This study compares the M-SEQ students filled in the two most recent SIS course editions. Seven students (16.3%) completed the experience questionnaire in 2021, and 10 in 2022 (17.5%), both within the expected average. The M-SEQ has two main categories of questions (described in Table 2): first, students must score certain criteria, then open-ended questions about course topics. These open-ended questions are divided into three categories: teaching practices that were useful or counterproductive, course improvement suggestions, and general comments.

The 2021 and 2022 SEQ mean, median, and grades did not vary significantly, and the students' general satisfaction with the most SIS-CBL version of the course is slightly lower[1]. Due to the low M-SEQ response rate, the median[2] usually drops less than the mean. SIS-CBL also had slightly higher mean scores for general (Q4-5)[3], marking (Q6)[4], teaching (Q7-10)[5], and testing (Q11)[6] questions. Students were more interested with course relevance to their degree than course-prior knowledge and course-learning objectives alignment.

According to open-ended questions, CBL and CBL mentors helped students create and implement their projects (OEQ1). They said they would have had a better experience if they had had access to the data earlier in the course or when choosing their project topic. In both versions of the course, students said tying lecture topics to projects and better organizing/distributing due dates will improve their SIS course performance (OEQ2). Finally, students say a storyline and potentially reducing the course's content would aid learning (OEQ3). Some students also regarded CBL as a promising tool for the SIS curriculum and suggested improving the lecture-project relationship.

Table 2. Questions of the Students Experience Questionnaire (SEQ).

Question #	Question description
01	Did I understand the learning objectives and assessment criteria?
02	Were course topics pertinent to the educational curriculum?
03	How well did the content of this course align with your prior knowledge?
04	Will the knowledge and skills acquired in this course quickly become obsolete?
05	Was the amount of time I spent studying for this course proportional to the number of credits granted?
06	How many points would you assign this course?
07	Did the instructional activities encourage me to study?
08	Did the faculty encourage me to think independently?
09	Did I feel that the instructor had a good understanding of how the students were coping with the subject matter and acted appropriately when required?
10	Did the course's feedback provide sufficient information for further study?
11	How would you rate the online examinations in this course?

[1]2022 mean: 6.6/10.0, 2021 mean: 7.0/10.0.

[2]2022 median: 6.0/10.0, 2021 median: 7.0/10.0.

[3]2022 mean: 3.5/5.0, 2021 mean: 3.7/5.0

[4]2022 mean: 6.7/10.0, 2021 mean: 6.6/10.0

[5]2022 mean: 3.5/5.0, 2021 mean: 3.4/5.0

[6]2022 mean: 7.1/10.0, 2021 mean: 6.4/10.0

3.4 Discussion

Research projects offered as part of a CBL approach can have a positive impact on students' performance. By engaging in hands-on projects that tackle real-world problems, students develop practical skills that complement the theoretical knowledge gained in lectures. Additionally, working on projects in groups promotes collaboration, communication, and critical thinking, skills that are highly valued. Moreover, students are encouraged to take ownership of their learning process by conducting research and finding creative solutions to problems, leading to increased motivation and engagement. This approach also provides students with an opportunity to apply their knowledge in a meaningful way, leading to a deeper understanding of the material.

The CBL mentoring process plays a crucial role in creating an enhanced learning environment. Mentors can provide guidance and support to students throughout the project development phase, helping them stay on track, identifying gaps in their understanding, and offering feedback on their work. This process also encourages students to take responsibility for their learning and develop self-directed learning skills. Mentors can also provide industry insights and connections, exposing students to potential career paths and helping them develop professional networks. By creating a supportive environment that fosters collaboration, critical thinking, and problem-solving skills, the CBL mentoring process helps students develop the confidence and skills necessary to tackle complex real-world challenges.

The challenges selected from predefined case owners can be effective in resolving real-world problems using CBL. These challenges are designed to be relevant and applicable to real-world scenarios, ensuring that students develop skills and knowledge that can be applied in the workplace. Additionally, by collaborating with case owners, students gain insights into the challenges and constraints faced in different industries, leading to a more nuanced understanding of the material. The challenges provide a structure for the project development process, helping students stay focused and on track. By leveraging the expertise of case owners and integrating real-world challenges into the CBL approach, students can develop a deeper understanding of the material, acquire practical skills, and build their confidence in tackling complex problems.

4 CONCLUSION

This paper has addressed two central questions for educators who are interested in implementing CBL while maintaining constructive alignment in their course design. The first question addressed how to ensure that the results derived from addressing student-defined challenges are successfully aligned with the course's intended learning outcomes. The second question focused on how to utilize these results as evidence of learning and as an assessment component. Our paper has presented our experience and lessons learned in applying CBL to the redesign and execution of the Smart Industry Systems course for Master programmes at the University of Twente. We have demonstrated that it is possible to implement a version of CBL while maintaining proper curriculum coverage and Constructive Alignment, and we consider valuable to other educators seeking to adopt CBL in their courses.

The presence of CBL mentors or specialists in a CBL-based course is crucial for the success of the learning experience. These mentors can provide guidance to both students and instructors, ensuring that the CBL approach is implemented effectively and that the desired competencies are being developed. Furthermore, having mentors or specialists who are knowledgeable about CBL can help identify potential challenges and provide solutions to overcome them. The need to meet formal evaluation and accreditation requirements may sometimes cause instructors to modify the CBL approach or include traditional teaching methods to satisfy these requirements. However, as the use of CBL becomes more widespread, it is essential that its principles are maintained and incorporated into the evaluation and accreditation processes. By doing so, we can ensure that CBL is recognized as a valuable approach to learning that can prepare students for real-world challenges and promote lifelong learning.

The implementation of a CBL approach can face limitations when attempting to align with a rigid curriculum that emphasizes fixed learning objectives. This can create a challenge in connecting CBL with Constructive Alignment, which seeks to align learning outcomes, assessment methods, and teaching strategies to achieve desired learning outcomes. The CBL approach prioritizes the development of specific competencies, which may not always align with the predetermined learning objectives of a curriculum. Therefore, the challenge is to find a way to integrate the CBL approach with the curriculum while still ensuring that students meet the required learning objectives. This requires a flexible approach to curriculum design and specialized human resources that enable the incorporation of CBL principles while maintaining the integrity of the overall curriculum.

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CUSTOMISING BEST PRACTICE IN STUDIES ADVICE FOR UNDERGRADUATE ENGINEERING STUDENTS

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***Keywords**: Studies Advice; Engineering Education; Student Engagement; Tailored Support; Advising, Tutoring and Mentoring.*

ABSTRACT

The attrition rates from undergraduate engineering programmes in the UK remains stubbornly high, despite the best efforts of course teams to engage and support students on their learning journeys. It is generally accepted that there is no single reason for attrition rates from engineering programmes being higher than from other vocational-type university programmes, but many academics believe that an effective Studies Advice system that works for students and staff, could lead to reduced numbers of disengaging and/or failing students.
Much has been written on effective approaches to the provision of Studies Advice at University, but it is not clear if the implementation of discipline specific approaches would yield better outcomes.
This practice paper describes work that is currently underway at Ulster University to examine engineering students' perspectives on the Studies Advice approach and to explore how best practice in the university sector might be effectively customised for engineering students. The work describes an initial scoping study, a co-creation exercise with students to establish their baseline understanding of the current system and their 'wish-list', and a follow-up focus group session where a number of discipline-specific interventions were explored.
Preliminary findings indicate that professional support departments could be more effectively integrated with academic support to provide a wrap-around or 'single contact point' for Studies Advice, that formal organised studies advice sessions should be explicit on programme schedules and that an informal 'buddy or mentor' student-to-student support system would be beneficial in addressing the UK engineering student attrition issue.

1 INTRODUCTION

1.1 Background and context

Pre-university entry profiles for engineering students in many UK universities are diverse and include learners from both academic and vocational backgrounds. The entry points to engineering programmes may also vary due to foundation degree (Fd) programmes which articulate to engineering degree programmes. Whilst this is to be welcomed from a Widening Participation and an Equality, Diversity and Inclusion (EDI) perspective it poses engineering educators with a series of specific challenges that are a 'work-in-progress' within the engineering education community. Work continues to find effective ways, and establish best practice, to support these diverse learners achieve their full potential in an academically demanding subject area.
Data from the Higher Education Statistics Agency (HESA) shows that whilst the 2019-20 non-continuation rate for engineering and technology of 5.3% is at its lowest level in the recent past, and is on a downward trend, it remains stubbornly high when

compared to other vocational-type university programmes that underpin professional registration such as law, medicine/dentistry/veterinary sciences or ‘subjects allied to medicine’. The HESA data also identifies that of those engineering and technology students who dropped-out of their HE courses, the most ‘at-risk-of-drop-out’ students were those who had pre-entry qualifications of ‘Level 3 + an equivalent A level’ closely followed by those students who had taken a BTEC qualification, with drop-out rates reported of 12.6% and 11.8% respectively for 2022. Much has been done to improve the attractiveness of engineering and to encourage schoolchildren pursue the STEM subjects; alternative pathways into the profession such as BTECs or T levels, etc. have been developed, but there is much work still to be done for educators to successfully retain and progress students in sufficient numbers through to completion of their engineering programmes and beyond.

It's clear that the UK’s Higher Education (HE) landscape for engineering is in a state of flux. The re-energised UK government focus on degree apprenticeships, the challenges industry faces recruiting sufficient numbers of high calibre graduate engineers, and a post-Covid student community who have not had the usual social, societal and developmental school experiences pre-university.

This practice paper examines best practice in studies advice for university students and proposes a practical, discipline-specific, ‘pick-n-mix’ or customised approach for undergraduate engineering students that will be relatively straightforward to administer and which, it is hoped, will better engage engineering students in their own learning journeys through the provision of timely and self-selected interventions.

1.2 Literature Review

It is broadly accepted that there is no single reason for non-continuation or attrition rates from engineering programmes being higher than from other vocational-type university programmes, but many academics believe that an effective studies advice system that works for students *and staff* could lead to reduced numbers of disengaging and/or failing students (Zepke & Leach 2005).

In general, academics relish their Studies Advisor role and enjoy that people-centred aspect of their academic role, despite the obvious time commitments such a role represents, given the large cohort sizes that are commonplace in today’s universities (Johnson 2016). Effective approaches to the provision of Studies Advice at University have been described previously but it is not clear if discipline specific approaches, tailored for given cohorts, would yield better outcomes. (Rolfe 2002) notes students from a vocational background are less willing to undertake independent study and demand more time and support from lecturers. Variability in the level of support expected and/or required by a diverse student cohort may not be obvious or easily recognised by academics and there are multiple points of failure in such a system.

(Cahill et al. 2014) indicate that student expectations and the nature of student support changes as students’ progress through their programme of study.

While approaches to the delivery of studies advice varies significantly between institutions (Habley, 1997) it is recognised broadly that advising / tutoring has both academic and non-academic aspects and supports students achieve “their academic and personal aspirations”. Four components of the UK Professional Framework for Advising and Tutoring (UKAT) shown in Figure 1 are described as Conceptual, Informational, Relational and Professional.

Fig. 1. (UKAT 2023) *The Professional Framework for Advising and Tutoring*

Studies advisors, it's argued, should have the appropriate knowledge and skills to support student learning and personal development at university and their professionalism or 'understanding' within the tutor-tutee space should enable them to connect students 'deeply' to their studies *and* institution.

In practice, most students engage with advice when they need to understand University policies, structures and procedures in making decisions (Kramer 2003) but it can also include students' aspirations and fulfilment (O'Banion 2009) as well as their wellbeing (Kramer 2003).

Engagement with advice is variable and is based on the needs of individual students (UKAT 2021) and the nature of student support that the students expects will change as student progresses through their programme of study, (Cahill et al. 2014).

One of the core categories in the UK National Student Survey (NSS) is Academic Support. The NSS is taken by students in the final year of their studies at all UK universities, and is an important external metric for universities, parents and prospective students. Despite Ulster University having a broadly uniform approach to Studies Advice, NSS results by programme are variable, once again indicating that students' perceptions are non-uniform even within a School. There are three questions that are asked under the Academic Support heading namely:

1. I have been able to contact staff when I needed to.
2. I have received sufficient advice and guidance in relation to my course.
3. Good advice was available when I needed to make study choices on my course.

In summary, there is much good practice in the sector and the challenge is how course teams can adapt that good practice and flex it to suit a local context and institutional preferences.

2 METHODOLOGY

2.1 Co-creation event

A sample (n=14) drawn from undergraduate engineering students in the School of Engineering and the Belfast School of Art and the Built Environment were invited to a co-creation event where;

1. their understanding of Ulster's current Studies Advice system
2. their perceptions of the effectiveness of Ulster's system and
3. their 'wish list' for an 'ideal' system

could be explored. Chatham House Rules was made explicit at the start of the session and students were arranged in groups of 3 or 4, and the sequencing of questions posed followed Kreuger's categories, (Kreuger, 1998).

The opening question for the co-creation required students to reflect on their experience of current studies advice in Ulster. This was followed by an introductory question on what works well and what works not so well in the current studies advice system. The key questions invited students to generate and share ideas on what an ideal studies advice system would be and how course teams might raise student aspirations and overall engagement within the undergraduate engineering student community. The ending questions closed with an opportunity for students to propose what makes a full and enjoyable student experience.

Kreuger's categories	Questions
Opening question	What experiences have you had of studies advice?
Introductory question	What works well in the current studies advice system?
Transition question	What works not so well in the current studies advice system?
Key questions	What would you like from an ideal studies advice system?
	How can we raise student aspirations and overall engagement?
Ending question	What can make a full and enjoyable student experience?

A basic content analysis of the students' views from the co-creation event, revealed three broad categories of views that we have termed; Academic, Operational and Guidance.
Interpreting and understanding the various studies advice category responses and the activities that the University might provide to support them were then explored in more detail, and students' understanding was checked in the follow-up focus group session.

2.2 Focus group

The focus group session was used to test students' perceptions on specific interventions that Ulster University could support, based on its current provision. Specific questions on the logistics of;

1. how the Schools could implement a user-friendly, low-overhead and practical approach, that would require students to select from a pre-set menu of possible interventions within each broad Studies Advice category, and
2. how those students' preferences could be streamlined and organised for each year 2 student on an undergraduate engineering programme.

In effect, how might we provide a customised studies advice experience for each student tailored to their specific needs.

3 FINDINGS

3.1 Understanding of current Studies Advice system and student 'wish list'

Tables 1 and 2 show students' suggestions from the co-creation events. Ulster University has a weekly timetabled Studies Advice session integrated within a specific 'Introduction to Engineering' module for first year undergraduate engineering students. Table 1 shows that this regular 'drip-feed' approach is valued by students (despite all students not engaging positively with it) and feedback in the Focus group event shows that there'd be merit extending it to year 2 students, particularly insofar as for widening access universities, such as Ulster, there are lots of 'new' students who join year 2 having previously completed a Foundation programme elsewhere. It's also noted that the performance of students in year 2, the so-called sophomores, tends to dip (as is the case more broadly), so improvements in the efficacy of the studies advice system would be welcome. The challenge is to encourage students to take charge of their own learning and personal development needs, recognise and accept that both developmental aspects are important, and be proactive in identifying and engaging with enhancement opportunities that are available to them.

Table 1. Operational wish-list

Operational - structure and scheduling of meetings		
Format preference	Frequency preference	Planning & scheduling
1-2-1	Week 1, 6 and 12 is ideal	Personally timetabled and personal/one-on-one support available on demand
Happy with online or in person	Year 1 Semester 1 weekly meetings and review helpful	Must be clearly communicated, studies advisors should be seen as available to students – currently students feel that they need to search a lot for help and often turn to peers for advice.
F2F preferable for many		Reminders sent for studies advice meetings

Table 2 shows the Academic support and Guidance that students would like from any studies advice system.

Table 2. Academic support and Guidance 'wish-list' from Studies Advice system

Academic support			Guidance		
Progression	Support	Skills development	Employability	Extra and co-curricular activities	Financial advice
Personal feedback on academic progress	Dealing with students who need learning support	Advice of how to study effectively	Provide support and advice on joining professional institutions	Focus on student experience, transition to university life	Advice on student finance options
Visibility and understanding of learning outcomes to aid progression	Understanding University regulations for my course	More early warning systems for coursework deadlines	Guidance on placement opportunities	Societies, Clubs, study trips abroad	Advice on grants and hardship fund availability
Enable students to consider research and development opportunities	Helping students who are struggling to pass modules	Improved social experience through study groups/ Student mentor system	Awards for hard work and to boost CV's welcome. Edge award/Global Engineer	Student jobs guidance	Signposts to scholarship opportunities

We have grouped students’ responses relating to personal development opportunities under the ‘Guidance’ category and it’s clear that students are indeed invested in seeking out extra- and co-curricular activites but anecdotally, uptake of these opportunities by engineering students lags behind students in other diciplines. Our preliminary findings support the argument that a studies advice system which is tailored to the needs of the student will encourage and empower students to take ownership of their learning (and by extension, embed a culture of lifelong learning) and to engage with those support systems that they believe will be of use to them.

3.2 Logistics of proposed customised Studies Advice system

It is proposed that the School develops an MS Forms questionnaire in line with EDI best practice on inclusivity. Studies advisors will administer the questionnaire to their year 2 students to complete in the first few weeks of the academic year. A series of questions using closed and open responses could be used to:

1. prompt students to reflect on their academic performance in the previous year of their course, and
2. identify areas that they’d like to see specifically focus on for development during year 2, and
3. prepare an enhancement plan from both an academic and personal development perspective.

A series of drop-down menus could be pre-populated with discipline-specific interventions, such as, Maths coaching, Studiocity, Library skills, SolidEdge skills, Matlab, etc. (ie areas that the Focus group identified as being useful) that are clickable so that students can select those activities that they have identified for enhancement. The School can then collate responses from all the year 2 programmes, organise and timetable activities centrally so that each student knows where/when to attend their selected enhancement activity, whether that be discipline-specifc support or personal development activities. The 1-2-1 tutor-tutee meeting can be much more clearly focused on the extent of the student’s achievement or on plans to overcome obstacles that may have arisen for any given student. It is expected that when students can see and recognise the ‘value’ in the studies advice meetings (which is enhanced by the student’s preparation and reflection) they should be motivated to engage more fully with the session.

The proposed approach will have the effect of educating students (and staff) as to what’s available for them (and how to navigate the professional support departments eg student wellbeing, student fees, employability, global engagement, etc.) and importantly, affording them the opportunity early in a semester to ‘opt-in’ and own ***their*** Studies Advice system and then attend those scheduled sessions that they have personally selected.

A working title for the new customised studies advice system is Academic and Personal Development Plan (APDP) but a more catchy acronym that includes ‘Engineering’ would facilitate staff and students buy-in and help embed the approach.

It is recognised that the questionnaire to be used will likely require ethical approval and this will be sought from the Faculty’s Research Ethics Filter Committee. Ulster University has a institutional Strategy for Learning and Teaching Enhancement known as SLaTE and the project team plan to submit a funding application to support this work in the next academic year.

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DEVELOPING GLOBAL ENGINEERS: A COMPARISON BETWEEN CHILE, SCOTLAND, AND THE UNITED STATES

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ABSTRACT

Engineering-accredited programmes are reviewed every 4-5 years by professional bodies with the aim of assuring standards that guarantee that graduate engineers can fulfil the highest technical demands of the industry workforce in order to achieve a sustainable economy and society. The approaches to develop these require global engineering competences (GECs), such as international and intercultural teamwork, language skills, critical thinking, and ethical and human-centered problem solving, are proving insufficient to meet the emerging challenges that this century's society is facing. To develop these GECs, engineering programmes have been working on including physical and virtual mobility such as Collaborative Online International Learning (COIL) together with other experiential learning interventions in order to provide the necessary requirements to become a global engineer. The aim of this practice paper is to compare and to discuss how three different universities, located in Chile, Scotland, and the United States have designed their engineering programmes to develop global engineers. This research provides preliminary results, based on an auto-ethnographic approach to analyse the curriculum design approaches and structures, that highlight opportunities for collaborative interdisciplinary experiences as well as more country- and institution-specific approaches (Engineers Without Borders) that support the development of these GECs. Analysis showed that the majority of the GECs are achieved by the three universities, however Virginia Tech is the only university that explicitly encourages and motivates other students through an assignment and cultural simulation activity. This research is part of a larger investigation that will analyse how engineering graduates perceive their development of GECs.

1. INTRODUCTION

Global engineering competences (GECs) have become increasingly crucial in today's interconnected world, where engineering projects and teams often span multiple countries and cultures. While technical expertise remains important, engineers must possess a range of competences beyond technical skills to be successful in the global engineering profession. These competences include cultural awareness, communication skills, ethical decision-making, and leadership abilities, among others (Bremer, 2008; Davis, 2018; Downey et al., 2006; Parkinson, 2007).

According to the Engineers Europe website and the EngineeringX website, GECs are critical for success in the 21st century engineering profession. The growing emphasis on addressing global challenges, such as sustainability, healthcare, and energy, underscores the need for engineers to possess the skills and knowledge to tackle these issues on a global scale. Additionally, engineering employers have found that technical skills alone are not sufficient for success in the engineering profession, and that professional skills such as communication and teamwork are equally important (SL Controls website n.d.). As a result, engineering education programmes are incorporating GECs into their curricula to develop engineers with the skills required for the contemporary workforce; and to ensure the sustainability of these engineering programmes, these GECs must be reviewed periodically in conjunction with the industry in order to respond to the changes/challenges caused by the constant evolution of our society and our economy.

Universities’ system differ from UK and America with regards the length of their undergraduate degree. In Scotland a bachelor’s degree in engineering can last between 3 to 4 years. Accredited 4 years degree allows to become chartered after few years of experience. In the United States of America, an engineering program at the bachelor's level generally lasts 4 years, whereas in Chile, the equivalent degree program typically has a duration of 5.5 years. Universities in the UK follow the UK Standard for Professional “Engineering Competence”. The universities in the United

States follow the Accreditation Board for Engineering and Technology (ABET) standards, while the universities in Chile are accredited by the National Accreditation Commission of Chile (CNA). However, these standards offer institutions flexibility in how they design their programs to meet these requirements (Engineering Council, 2023; ABET website, 2021, CAN website, 2023).

To prepare students for success in a global workforce, universities have developed different strategies and interventions that provide opportunities for students to be exposed to the complexities of developing GECs (Sharma and Alvi, 2021). While international experiences are important, it is also crucial to establish a collaborative dialogue among experts, including academics, industry professionals, and higher education decision makers, to create effective learning outcomes that help students develop GECs (Moore, 2022; Ortiz-Marco, 2020).

This practice paper focuses on an ongoing project among University Austral in Chile, Glasgow Caledonian University in Scotland, and Virginia Tech in the United States. The project aims to reflect on and compare the approaches taken by each institution to develop and achieve GECs.

2. THE GLOBAL ENGINEERING COMPETENCES: A FRAMEWORK

Global engineering competences (GECs) have become a topic of interest for researchers in recent years, as they play an essential role in the success of engineering professionals in a globalized world. The Engineers Europe website and the World Economy Forum website (2021) have identified several key GECs, including technical, cultural, communication, ethical, leadership, entrepreneurial, and global competences. Other studies have emphasized the importance of professional skills such as communication, teamwork, and leadership, in addition to technical skills, for success in the engineering profession. Research suggests that industry recognizes the importance of these skills, with communication skills being particularly valued. Additionally, cultural awareness and the ability to work in diverse teams are also considered important for success in the global engineering profession.

For the purpose of this practice paper, the comprehensive list of global competences identified by Ortiz-Marcos (2020) will be used as the framework. These competences were collected through an extensive interviewing process with engineering companies located in five European countries, providing valuable insights into the most valued skills and knowledge in the global engineering profession.

Downey et al. (2006) argue that GECs must include developing the knowledge, ability, and disposition to work effectively with people who define problems differently than oneself. Hence, to understand and assess GECs better, it is essential to understand how different universities in different countries perceive the development of GECs. Johri and Jesiek (2014) have suggested a broader approach to defining global engineering competency as the capabilities and job requirements that are uniquely or especially relevant for effective engineering practice in a global context. They argue that the attributes of a globally competent engineer belong to three dimensions: technical coordination, engineering cultures, and ethics and standards and regulations. Table 1 provides a fusion between three dimensions proposed by Johri and Jesiek (2014) and the global competences suggested by Ortiz-Marcos (2020). It is noteworthy that while some competences may belong to one of the three dimensions, there are others that can be transversal and, therefore, not associated with a unique dimension. Communication is an example of a transversal competence.

Table 1. Dimension/Definition and suggested Global Competences (Adapted from Johri and Jesiek 2014 and Ortiz-Marcos 2020)

Dimensions	Definition	Global competences
Technical coordination	It involves managing social relationships and communication in multinational/cultural settings, with a focus on technical experts and problems. It differs from cross-cultural business or management situations, which do not necessarily involve technical expertise or issues.	GC1:Communication GC2:Communication in a foreign language GC3:Holistic system thinking GC4:Negotiation GC5:Conflict management GC6:Cooperation GC7:Problem solving GC8:Encourage and motivate others GC9:Teamwork GC10:Understand the connectedness of the world GC11:Decision making
Engineering cultures	They refer to the diverse practices and processes of technical problem solving across different multinational and cultural contexts. They are characterized by a strong focus on technical expertise and technical problems.	
Ethics, standards, and regulations	This category arises when technical coordination or problem solving occurs amidst conflicting normative and policy contexts.	

3. METHODOLOGY

Although this is a practice paper, we consider it important to report on how our analysis and the preliminary results were identified and presented. Our work is informed by an auto-ethnography approach; which is a qualitative research method that promotes self-inquiry in a critical way that involves reflection and narrative inquiry (Hughes and Pennington 2017); this means that there is a high content of self-reflection which allows the researchers to be the objects of study while having the flexibility to position themselves in relation to the phenomenon of study (Hughes 2020). We considered this an appropriate method to share our combined experiences and our critical reflective process of how our institutions in each country develop GECs. To conduct the comparative analysis, we defined a qualitative scale to assess the degree of alignment or congruence between competences from specific engineering programs and the GECs (Ortiz-Marcos 2020.The scale presented for evaluating the indicators of performance was derived from a combination of the authors' experiential knowledge, professional judgment, and the application of the auto-ethnography approach. Based on experiences and expertise in the field, the authors reached at a consensus on the development of the following indicators of performance:

1. Not Aligned (NA): no significant overlap or agreement between the GECs and the outcomes competences of the specific engineering programme. In other words, the skills and knowledge that are emphasised in the programme do not match with the competences that are required for engineering practice on a global level.

2. Partially Aligned (PA): some overlap or agreement between the GECs and the outcomes competences of the specific engineering programme. Some of the skills and knowledge emphasised in the programme match with the competences that are

required for engineering practice on a global level, but there are also significant gaps or areas where there is no alignment.

3. Fully Aligned (FA): high degree of overlap or agreement between the GCECs and the outcomes competences of the specific engineering program. The skills and knowledge emphasised in the program closely match with the competences that are required for engineering practice on a global level, indicating that the program is well-designed and relevant to the needs of the industry.

In the following section, we describe the different institutions, programmes, and at the end we provide the table that summarises how we self-assess our GECs development.

4. DEVELOPING THE GLOBAL ENGINEERING COMPETENCES: THREE CASE STUDIES

4.1. THE CASE OF CHILE

University Austral was established in 1954, where The Faculty of Engineering Sciences, founded in 1989, offers eight undergraduate programmes, five master's programmes, and two diplomas.

In this study GECs for mechanical engineering and industrial engineering will be analysed. These two programmes are a five-year degree where students are required to take a course in communication in a foreign language (English) during their first semester and a general communication course during their second semester. Although engineering students are required to read and review various English resources throughout their programme, courses related to technical competences do not typically require verbal or written communication in English.

The mechanical engineering programme stands out for its incorporation of the problem-based learning (PBL) methodology, where six modules use this approach offering practical experience in solving real-world problems. The PBL courses are offered from year 3. The projects involve interaction with real stakeholders, especially those dealing with issues like water supply, energy supply, and domestic and industrial waste management. Additionally, the programme includes a one-semester professional practice and a final project. Notable outcome competences linked to this programme include problem-solving, teamwork, cooperation, and decision-making.

In the case of industrial engineering, students are required to take an English communication course for four semesters and a general communication course for two semesters. Also, communication and teamwork competences are developed during the professional cycle of the programme through collaborative projects across various subjects. These projects are usually presented to classmates, but only in Spanish (students first language). Problem-solving is a skill that is enhanced throughout the degree through professional practice and a final project that requires students to analyse and solve engineering problems in real-world contexts. The final project also contributes to competences such as cooperation, holistic systems thinking, and decision-making. Although students have a sponsoring teacher, they enjoy considerable autonomy in selecting the organisation where they will develop their project, the topic, and the approach.

The University also offers optional student exchange opportunities with foreign and national universities. These exchange opportunities contribute to the strengthening of global competencies.

4.2. THE CASE OF SCOTLAND

Glasgow Caledonian University was established post 1992. Among all their programmes it offers a total of 5 engineering programmes at undergraduate level which includes mechanical engineering. Glasgow Caledonian University's Strategy 2030 is underpinned by UN SDGs and has been developed to respond to these demands where a transformative education is key to develop globally competent graduates. Technical, communication, ethical, leadership and entrepreneurial competences are achieved through the degree by different types of activities/assessments included in different modules. In the first year students are introduced to ethics and practices, engineering responsibilities and challenges of the engineering profession such as in the Engineering for Society module. Team building/skills are key in engineering and these are introduced from 1st year.

Recognising the importance of GECs, 2nd year students take part in compulsory four weeks virtual mobility activity, such as Collaborative International Learning (COIL), where students not only gain knowledge in the area of engineering, but also develop cultural awareness, international perspectives, and ethical sensitivities. This activity is deliverable included as not all students take part in international collaboration due to different personal commitments. From 2nd year onwards students are involved in Problem-Based learning (PBL) and in modules such as Integrated Engineering Studies (3rd year) where a business case study is included; in these modules, the best projects get to enter the Engineers without Borders: Engineering for People Design Challenges competition. The final year project gives students the opportunity to showcase all competences developed along with their degree and the opportunity to analyse and solve an engineering real life problem. The university also provides opportunities for students to participate in physical mobility through international exchange for level 3 students (few examples: Touring Scheme (former Erasmus scheme), European Project Semester, International Project Week, Engineering vision, etc.) and the possibility to apply for a Year in Industry programme just after 3rd year to gain industrial experience before returning to the final year of their degree.

4.3 THE CASE OF USA

Virginia Tech, College of Engineering, among all their programmes offers 14 undergraduate degree-granting engineering majors.

For this study, the Rising Sophomore Abroad Program (RSAP) was selected. This program provides first-year engineering students with an opportunity to expand their global competences through an international experience. RSAP integrates an on-campus, Spring course on Global Engineering with a short-term international module immediately following semester exams. The class during the Spring semester meets for three hours each week including 2 hours of lecture and 1 hour of travel development according to students' individual tracks. Each year the program has multiple international tracks where students travel to different parts of the world. This pre-trip attention has helped the students make the most of their short-term study abroad experiences. Similarly, the course has 3 modules associated with 3 mini project that students complete: 1) Global Challenges, 2) International Preparation, and 3) Global Communication. At the end of the Spring semester, students travel abroad on one of the multiple international tracks for a period of two weeks. The program tracks have included the following countries: 1) China, 2) the United Kingdom and Ireland, 3) Italy, Switzerland, and Germany, 4) Chile and Argentina, 5) Spain and Morocco, and 6) Australia and New Zealand. To meet the program’s goal of global engineering competences, students visit companies, universities, and are immersed in cultural and social attraction sites in the respective host countries.

Table 2 summarises the GCs achieved by the three universities involved in this study.

Table 2. Summary of the Global Competences achieved by each of the three universities involved in this study

Global Competences	University		
	Austral	Glasgow Caledonian	Virginia Tech
GC1: Communication	FA	FA	FA
GC2: Communication in a Foreign Language	PA	NA	NA
GC3: Holistic system thinking	FA	FA	FA
GC4: Negotiation	PA	PA	PA
GC5: Conflict management	PA	PA	FA
GC6: Cooperation	FA	FA	FA
GC7: Problem solving	FA	FA	FA
GC8: Encourage and motivate others	NA	NA	PA
GC9:Teamwork	FA	FA	FA
GC10:Understand the connectedness of the world	FA	FA	FA
GC11:Decision making	FA	FA	FA

NA: Not Aligned- PA: Partially Aligned- FA: Fully Aligned

5. DISCUSSION

As observed from the results the three universities provide opportunities for students to develop GECs. When analysing Table 3, the majority of the GCs are achieved by the three universities involved in this study, however GCs 4, 5 and 8 are either NA or PA. The reason for this decision is that these competences are implicit when working in teams, but not explicitly defined as a learning/skill outcome.

Additionally, as mentioned in Section 2, language and cultural skills are one of the skills required to be a global engineering and as observed in Table 2, GC2: Communication in a Foreign Language is NA for Glasgow Caledonian University and Virginia Tech and PA for University Austral where English language must be taught in the first years of the degree. English is considered an international language, 510 million people use English Language to communicate daily and there are 53 English speaker countries around the world (Hammond 2014). This is an obvious advantage that students from Scotland and USA have compared to students from Chile.

Regarding GC8: Encourage and Motivate others, Virginia Tech, is the only university that explicitly addresses this competence through an assignment and cultural simulation activity. The assignment is focused on understanding what is required for a student to work on an international team with an explicit focus on how to lead others to engage in productive conversations and work. Similarly, the cultural simulation activity has the goal to understand cultural differences but also to motivate others to do so.

The Global Engineering Competence 'International opportunities' was highlighted as highly important by industries (despite not included in Table 1), however it is an important aspect considered by the industry when recruiting engineers, as graduates that have taken part of an international experience show adaptability, resilience, cultural and self-awareness (Ortiz-Marcos 2020). Following this, Glasgow Caledonian University provides the opportunity to study abroad, however taking into account personal challenges students might face that impact their opportunities to experience physical mobility, Glasgow Caledonian University included a compulsory activity in level 2 which is a Collaborative Online International Learning (COIL) experience (virtual mobility). This helps to become responsible global citizens through the development of intercultural competences, ethical sensitivities and international perspectives at the same time that provides teamwork and dynamic skills while it is used as an opportunity to compare international variations in engineering education and practice and an understanding of business and engineering cultures of countries involved. It also provides equal opportunities to all learners to experience an international experience.

6. CONCLUSIONS AND FUTURE WORK

In this practice paper, we have presented our initial findings from an ongoing research project that aims to identify the opportunities and challenges in bridging the gap between global competences (GCs) and outcome competences in engineering programs at three universities. Our analysis suggests that while GCs such as "holistic system thinking," "communication," "cooperation," "problem solving," "teamwork," "understanding the connectedness of the world," and "decision making" are fully developed in the programs at these universities, there are other GCs that require further attention.

For instance, our study indicates that all three universities could benefit from emphasizing communication in a foreign language and providing tools to develop competencies in negotiation and encouraging and motivating others. Additionally, the results suggest that universities can learn from each other to reduce the gap with respect to certain GCs. For example, University Austral and Glasgow Caledonian University could learn from Virginia Tech’s approach to acknowledging and addressing the competence of "conflict management," and University Austral could adopt the learning strategies used by universities of Glasgow Caledonian University and Virginia Tech to promote international interaction among engineering students.

Furthermore, we suggest that virtual mobility can serve as an effective option for addressing different GCs, particularly when "real" mobility is limited. This approach can help students gain skills such as adaptability, resilience, cultural awareness, and self-awareness. Overall, our study highlights the need for continued efforts to address the gaps between GCs and outcome competences in engineering programs and suggests several ways in which universities can work together to achieve this goal.

Moving forward with our ongoing project, our next steps will involve conducting a quantitative analysis of the engineering programs at the three universities to determine how they are addressing GCs. Specifically, we plan to distribute surveys to students to gather data on how they perceive themselves as global engineers. This data will help us gain a deeper understanding of the students' perspectives on their own competences and identify any areas where further improvement is necessary. The results of this survey will provide valuable insights into the effectiveness of current teaching practices and the potential for future improvements to address the gaps between GCs and outcome competences in engineering programmes.

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AN AUTOETHNOGRAPHY OF BECOMING AN INNOVATIVE ENGINEERING ACADEMIC: PUNK, PIRATE AND GUERILLA PEDAGOGY

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Keywords: disruptive pedagogy, identity, risk, epistemic, scholarship

ABSTRACT

In this Autoethnography (AE) I consider, "becoming" the Most Innovative Teacher (2018) at my university. My identity as a university teacher, my epistemic beliefs, and my choice of vocational pedagogical techniques, have been influenced by my working-class background. No school qualifications, becoming the wrong sort of engineer (plumbing), and a twenty-three-year journey to a doctoral qualification. In 2013 my employer declared that I did not have a 'significant responsibility for research' (SRR). I was transferred to a teaching only contract as a punitive measure for not fulfilling my employers research expectations. My lateral migration to a teaching post was the catalyst for my re-engagement with pedagogy. I became aware that my teaching & learning practice had theoretical (constructivist) foundations. Engaging in scholarship, I read publications on teaching like a pirate, guerrilla teaching, and being a punk educator. It became clear that I had taken similar risks, to do engineering education differently. In this paper I will examine what motives I had for going "off-piste" and, whether my practice truly constitutes "innovative" engineering pedagogy. I conclude with a caveat on the research methodology (autoethnography) employed.

1 INTRODUCTION

1.1 Positionality

I work in the construction industry. Whilst I may no longer be a 'construction worker', my academic identity, and my ontological and epistemic beliefs, have an indelible link to my post-school employment (1980-1984) as an apprentice plumbing & heating engineer. Through reflecting on these early work years in adult life I now understand why I am drawn to Constructivist pedagogies. As an apprentice, I learned 'on the

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job', and, at college. A symbiotic relationship espoused by Ryle (1945) as the practical 'knowing how', and the theoretical 'knowing that'. My apprenticeship experience has put a 'vocational' stamp on my approach to teaching and learning in Higher Education (HE).

The purpose of this paper is to 'go public' and to offer a transparent account of why, and how I have made changes to my teaching practice. The catalyst for my reflections being an award (most innovative university teacher, Student Union Teaching Excellence Awards, 2018 -TEAs) at Strathclyde. What 'innovative pedagogy' had I deployed? Had my students gained an advanced understanding of what constitutes innovative pedagogy? Did the evaluation panel have rigorous criteria for defining and evaluating innovative practice? I think not! As Averill and Major (2020) have argued, 'innovative pedagogy' is a term that is challenging to interpret.

2 METHODOLOGY

2.1 Autoethnography

AE is qualitative research methodology that places the author as an insider participant observer of their own practice. Ellis, Adams & Bochner (2011) note that AE researchers 'use tenets of autobiography and ethnography to do and write autoethnography. Thus, as a method, autoethnography is both process and product'. AE researchers revisit their practice through epiphanies / life events and use selective judgement to narrate episodes that are salient to the story. Given the recent disturbance to academia (coronavirus pandemic) Waller and Prosser (2023) have called for a greater use of AE as a means to explore the lives of academics.

In engineering education, the use of AE is sparse, albeit with a recent spike (i.e., Chambers et al., 2021; Secules et al., 2021; Xu, 2023). One study (Martin, Bombaerts, & Johri, 2021) published by SEFI. Of particular relevance to my own cultural identity, AE has been employed by former tradesmen in doctoral research (Moffat, 2018 (car mechanic); Crascall, 2021 (carpenter & joiner) to chart their own transition from blue-collar to white-collar academics. Through consultation with AE research on academic identities in HE (Trahar,2103; Kumar, 2021) and I believe that my approach combines an evocative (confessional) and analytical (objective) style of AE.

3 FOUNDATIONS OF KNOWLEDGE

3.1 A Plumber and an Anaesthetist

My exit from secondary school in December 1979, with no qualifications, was a case of social engineering. Whilst my brother (anaesthetist) was preparing to graduate from the same school as Dux, and study medicine at Edinburgh University, I found myself enrolled on a pre-apprentice, construction trades 'link- course' at my local college. Rose (2014) refers to similar practice in the USA whereby 'neck down', non-cognitive, non-academic, manually minded students, are streamlined into vocational, physical work pathways. In the UK, Claxton (2015, 270) notes that- 'despite repeated attempts to redress the balance, 'vocational' or 'technical' education is still widely seen as what you do if you are not 'bright enough' to do well at English, Maths or Science.'

3.2 A Love for Learning

The pre-apprentice course led to an apprenticeship as a plumber (1980-1984) and a further two years practising my trade. Unknown to me at the time, this was my introduction to experiential learning within a Community of Practice (Wenger, 1998); reflecting on, an in practice (Schon, 1983), and critical, a love for learning that was absent in my schooling. Over the piece (1984-86) I continued part- time day studies at college (unusual for trades) and secured an Ordinary National Certificate (ONC) in Building Studies. On symbolism, I recall a pride in purchasing a scaled ruler for the course, not quite a highbrow log scale ruler, but something with numerical significance that demonstrated a ‘neck-up’ learning opportunity!

3.3 Ballcocks and Bernoulli

It was not just ballcocks, boilers and blocked drains that formed my identity. I have taken some kudos from knowing that my craft knowledge on water and gas pipe sizing had scientific origins (Bernoulli's Theorem). Inductive learning oiled my cognition, and again, unknown to me at the time, was my introduction to learner agency, learning how to learn (metacognition) and, heutagogy- self determined learning (Hase & Kenyon,2013).

In 1986 I was presented with an opportunity to take on a temporary role as a plumbing lecturer at Perth college. Serendipity played a part in my first full-time appointment (1987-1988) at the Borders college (I replaced the successful candidate who was homesick after two months!). This employer blocked my request for further academic progress, so I embarked on a new lecturing job (1988-1992) at a college in England. During this period, I solidified my disciplinary knowledge through securing a Higher National Certificate (HNC Building) and a teaching qualification (Certificate in Education).

3.4 Follow Your Learning Heart- Not the Money

By 1992 I had grown restless and my HNC provided access to full time study- BEng (Hons) Building Engineering & Management degree in Edinburgh. I graduated 1st class with a university medal and continued to study MSc Construction Management, graduating 1996. During the summer vacations I went back ‘on the tools’ and between 1994-1996 I also undertook part-time work teaching plumbing at Perth college, in parallel with my studies. On completion of my MSc, I secured part time teaching at Robert Gordon University (2 days); 1 day at Fife College, and 1 day at Borders College. I had become a jobbing academic, tramping for work. By spring 1997 I had secured a full-time lecturing post at Robert Gordon University and enquired about part-time doctoral study, but I was turned down. Not to be discouraged I accepted a Research Assistant (RA) post and funded doctoral study at the University of Strathclyde, starting in January 1988. I recall my head of department at Robert Gordon asking- “surely you are not going to take a £10,000 pay cut to take up the RA post?” In October 1999 I secured a lecturing post at Strathclyde and completed my thesis in 2003. This rounded off a twenty-three-year learning journey (Pre-Apprentice Certificate-City & Guilds-ONC-HNC-BEng (Hons)-MSc- PhD). For my reward my annual salary was lower that what it would have been had I stayed in-post as a college plumbing lecturer!

4 I Fought the Research Excellence Framework (REF)

In the UK, the REF gives added emphasis to the maxim of ‘publish or perish’. In 2013 my university declared that I did not have a ‘significant responsibility for research’ (SRR) and I was transferred from a lecturing post to a ‘teaching fellow’ category. Most UK universities have played this game, to maximise their income stream from the REF exercise. During the 2013-2015 period I developed a vitriol for my university, and a metrics culture instilled by the REF. This period allowed me to construct an identity of ‘who I was not’, as much as ‘who I would become’. If my institution was not walking the talk on the Scholarship of Teaching and Learning (SoTl), then I would. Enrolling on a PG Certificate Learning and Teaching in HE course was a start, engaging in engineering education research followed. I embarked on changing my teaching an assessment practice, becoming more ‘guide on the side’, to encourage student agency. Over the piece I have taken comfort in the words of a former ICE President- ‘it is hardly an overstatement to say that the soul and spirit of education is that habit of mind which remains when a student has completely forgotten everything he has ever been taught’ (Inglis, 1941,3).

5 Pirate, Punk, Guerrilla: Cosplay or Constructivist Pedagogy by Another Name?

Over the piece I gained confidence in my epistemic believes through reading works by like-minded scholars. Claxton and Lucas (2015) talk of replacing the school exam factories with curiosity-based learning. Similarly, Calman (2019), a former vice-chancellor at Durham university- ‘universities are not meant to be degree factories’ (p139) and a former vice-chancellor of my own university (Sir Graham Hills)- ‘Universities are Socratic by conformity. Dissent is their life blood. No one worthwhile joins a university to be told what to do’ (Hills and Lingard, 2004, 224). I found publications on punk, guerrilla, and pirate pedagogy that bolstered my confidence in declaring that I had become an advocate of constructivist pedagogy.

5.1 Punk

In ‘*Being punk in higher education: subcultural strategies for academic practice’* Parkinson (2017) provides an analysis of interviews with five HE teachers (humanities) who self-identify as punks, seeking to uncover their punk and academic identities. He adds his own perspective – ‘I have always identified with punk practices, ethics and culture, all of which are woven into my lifestyle and worldview’ (148). Whilst ‘specific examples of applying punk practices through pedagogy were relatively sparse’ Parkinson’s analysis led to three broad themes related to the participants application of punk in their teaching. (1) Performativity-Issues related to resisting the status quo through individual and collective actions (2) Autodidactic and amateurism-whereby participants sough to encourage students to take responsibility for their own learning, to resist the techno-rational and banking models of higher education. Through providing students with agency to engage in self-directed learning (3) Experience and praxis-an emphasis on valuing students’ prior learning and promoting experiential learning and reflective practices. Parkinson concluded that the interviewees did show aspects of ‘reactionary disposition’ and that they had used a ‘grand punk narrative’ as ‘a mythological tool, encapsulating and ennobling their ethical frameworks and validating their responses to the pressures of academic life in a troublesome higher education climate (156).

5.2 Guerrilla

Guerrilla teaching (Lear, 2015) is a call to arms for primary schoolteachers to embrace their inner oddball, to be creative in their pedagogy, model curiosity, and bring a joy of learning into the classroom. Lear has a healthy disrespect for Government (Ofsted) interventions in UK schools and the associated collateral damage associated with the tyranny of metrics and league tables (teaching to the test). My attraction to going guerrilla is based on my own practice of 'just do it', to take risks and to try something different in my learning and assessment practice. Lear refers to his preparation in the classroom before his pupils arrive: 'just before I open the door, the music will go on. Three tracks (the same ones every morning) that make me smile, or-on a really good day-dance '(30). He explains the need for teachers to radiate happiness and optimism- 'thanks to my morning songs, even if I'm tired and fed up, there's always a smile on my face as the children come in' (p.36).

5.3 Pirate

Burgess (2012) a schoolteacher in the USA offers guidance for 'mavericks and renegades who are willing to use unorthodox tactics to spark and kindle the flame of creativity and imagination in the minds of the young' (p.xii). In his book -*Teach Like a Pirate,* he encourages educators to adopt the spirit of pirate mythology, to be bold, take risks and adopt creative practice. In -*Kill your PowerPoints and teach like a pirate,* Arvanitakis (2012) explains his reason for adopting unconventional inductive teaching methods (i.e., flashmob, body percussion) before introducing theoretical concepts in his first-year classroom. His approach is based on affording student's agency and encouraging citizenship through the use of contemporary and relevant case studies. Law (2013) teaches *Building Services Like a Pirate* to his fourth-year architects. He employs music and rhythm to teach space planning in buildings and with refence to the location of toilets (blocked and leaking) developed a 'Sewer Rap' to emphasise that 'shit happens'. In an exercise to teach building codes (fire egress and firefighting requirements) he arranged for Tasmanian Fire Service to disarm the alarm system and fumigated the lecture theatre with a disco fog machine! Law's dramatic approach is reminiscent of Estes (2007) *Shock and Awe in the Civil Engineering Classroom*.

6.0 Innovative Pedagogy?

In this section I provide a synopsis of practice that have I introduced in a first-year civil engineering module (Civil Engineering & the Environment). Expanded case studies (*) with student feedback can be found on a University of Strathclyde (2023) platform- Sharing Practice in Effective Learning and Teaching (SPELT). Several interventions predate my reading of Sambell, et-al (2012) *Assessment for Learning* (Afl), yet all have elements of Afl. As Brookfield (2017, 171) has noted, 'reading educational literature can help us investigate the hunches, instincts, and tacit knowledge that shape our pedagogy'. Several interventions introduced 'playful learning' (collage, rich picture, newspaper front cover). I did not undertake a risk analysis, consider failure, or worry about what my colleagues, or my students would think. It is reassuring to find other 'oddball academics' engaged in similar practice in the engineering classroom (Willis, 2009). However, James and Brookfield (2014) warn that educators who employ playful learning should guard against accusations of 'edutainment'. Moreover, Lanagan (2011) posits, 'is it [edutainment] a dirty word whispered in contempt of traditional approaches that implies a dumbing-down of content, whilst glamorising the superficial?' (1).

6.1 Industry Magazine Collage Coursework 2008-2010

To demonstrate the breadth and dept of civil engineering practice I used industry magazines (*Construction News* / *New Civil Engineer*). The magazines were used to inform an individual written report, and in groupwork cut and collage sessions, to promote fun, foster creativity and reinforce the useful learning from their reading. I contacted the editors of both publications, and it was agreed that the groups with the best collages (voted on my industry guests) would receive one-year subscriptions (Construction News, 2009, Oliver, 2010). Brookfield (2013) has suggested that using collage with students can reduce their fear of engaging in art-based exercises.

6.2 National Geographic*

I sought to introduce my students to civil engineering through a global lens (globalization, ethics, nature, environmental impact, people, and planet). I distributed recent editions of *National Geographic* (NG) and tasked my students to find stories that they considered relevant to their discipline. The results from a pilot study, and a content analysis of a number of editions from over a decade revealed that NG regularly carries themes directly concerning the impact of civil engineering in society (Murray & Ross, 2014).

6.3 Newspaper Front Page Coursework*

Students were tasked with finding stories about civil engineering practice in local and national newspapers. To aid a liberal education through the setting of civil engineering within the social as well as technological environment. The groupwork task involved students preparing their own front page for a civil engineering newspaper and they were encouraged to be playful and humorous in the text and graphical images used to convey their new knowledge. I arranged for colleagues from another department (journalism) to vote on the best front page and the authors were awarded a book prize.

6.4 I'm the Student ICE President Address Coursework 2009-2019*

In this coursework I adopt Sir Isaac Newton's 17th century dictum – *'if I have seen further, it is by standing on ye shoulders of giants'.* I assembled a folder with the inaugural addresses of the ICE presidents (1820 onward) as they constitute a living history that charts the scientific and technological innovations in civil engineering. Students were required to consult six addresses (two from each century) and use these to aid their own address. Reference to contemporary issues and foresight towards 2050 were expected. The top five graded students would present an abridged version of their address to the next 1st year cohort and these students would vote on who would be the student ICE President. The winners received an industry sponsored (BAM Nuttall) trip to the ICE HQ in London and a site visit to a large project such as Crossrail / Thames Tideway, (Murray and Tennant, 2016).

6.5 BBC Reporting Scotland Coursework 2016-2019*

I used my university Planet eStream facility to record weekday BBC Reporting Scotland (6.30-7.00pm) programmes. Where issues relating to civil engineering were present these editions were saved and logged with a title and an indication of the stream slot. On occasions, one broadcast could have up to three topics of interest (i.e., renewable energy; infrastructure projects; bicentenary of a civil engineering structure). Students were required to select four streams to view and to complete a table with details about what they considered the theme / subthemes of the story. In addition to make a judgement about how news uses ‘frames’ (conflict, human, economic, morality, responsibility) to convey certain aspects of a perceived reality.

6.6 Rich Picture Coursework 2019-2023*

Since 2010 I have recorded (Plant eStream) a variety of television and radio broadcasts that have relevance for the civil engineering profession. My portfolio includes biographies of civil engineers (i.e., Telford, Brunel, Stevenson’s); project specific (i.e., London Crossrail, Edinburgh Trams) and discussion (i.e., Elon Musk's Hyperloop and Brunel's Atmospheric Traction Rail). I use two popular series (World’s Greatest Bridges / Britain’s Greatest Bridges) for the rich picture. In groups of four the students select one different bridge and watch the programme. They are reminded that these programmes are produced for public viewing, and they should interrogate them as civil engineering students. On the day the students are provided with coloured pens and flip chart paper and tasked with creating a group rich picture.

6.7 International Poster Coursework 2015-2023*

The premise for this initiative is based on the need for graduate civil engineers to have a global outlook and to appreciate different cultures and customs. Students work in groups of four and are allocated an international mentor (a peer first-year; senior undergraduate; post-graduate; Erasmus / International student visitor) who has volunteered to talk to the group about culture and customs in their home country. In addition, to suggest typical significant civil engineering structures and buildings in their hometown / country, that students could go away and research. The group are required to produce a large poster with sketchers of these buildings and structures and annotate with text describing some of the salient features. To date this has involved over one-hundred international mentors representing fifty-three different countries.

6.8 Reading for a Degree-A Compulsory Book Reading Coursework & Department Book Club 2009-2015 *

Each year, the freshers were required to read one book from four. The books selected for reading were chosen on the basis that they provided knowledge about the history and heritage of civil engineering including biographical text and / or contemporary accounts of inspirational civil engineering projects. I established a department to run in parallel with the coursework to provide a platform to invite book authors to the department. Excursions   were also undertaken to meet book authors and undertake readings at associated structures. During the 2018-2019 session I developed a ‘trojan horse’ book reading to allow students to visit civil engineering consultants’ offices (Arup and AECOM) to meet book authors, then, to meet graduates and undertake a tour of the offices to learn about industry practice.

6.9 Book Jigsaw Coursework 2016-2023*

During my studies (PG Certificate Learning and Teaching in HE, 2015-16) I was introduced to the concept of flipped learning and the jigsaw classroom (Voyles, Bailey, and Durik, 2015). This influenced my thinking and I replace the compulsory book reading with a book jigsaw exercised whereby students worked in groups of four. Each student reads a different chapter of an allocated book and during the jigsaw session the following week the students function as teachers to explain to each other key learning from their chapter. I extended this practice with relevant books in my 3-5th year modules. The coursework requires students to write a report on what they consider to be the key learning from each chapter (with associated research) and to reflect on collaboration and communication skills (own and peers) during the jigsaw.

7 Discussion

7.1 Pedagogical Innovation?

In writing this paper I am minded that my pedagogical interventions could be considered as ‘show and tell’ practice, lacking in transferability, and without sufficient rigour to be considered ‘research’. Should readers adopt / adapt these initiatives in their own institution, I can offer no evidence to corroborate a link between my own practice and being designated as an innovative university teacher. However, Walder’s (2014) research in Canada (academics concept of pedagogical innovation) does provide a benchmark for comparing my practice. Walder interviewed thirty-two academics (recipients of excellence in teaching awards) and established a framework of seven distinctive notions of the concept of pedagogical innovation. Pertinent to my own practice are- *Novelty* (not following tradition, surprising students, using methods contrary to main tendency) and with relevance to punk, pirate, and guerilla pedagogy- *Human relations* (taking risks, innovation intimately linked to the teacher’s personality, innovation is learning as a professor). A link to this paper is apparent- ‘Pedagogical innovation stems from very personal origins within the university teacher, who appears to seek to move towards their pedagogical ideal’ (p.200).

7.2 Autoethnography, or something else?

In this paper I have sought to employ AE as a research methodology. However, just because I say it is an AE, does not mean it is! ‘There can be a messy boundary between autobiography and autoethnography’ (Lapadat, 2017, 590) and this paper does perhaps lean towards an autobiographical account. In retrospect, I removed too much narrative from my draft paper where I speak in my own voice (one of the key tenets of AE). I had concerns that this version would have attracted a common criticism of AE research being self-absorbed, self-indulgent, and self-celebrating (Lapadat, 2017). My draft paper contained extracts from my evocative poetry (*Pedagogy in a F****** Box*) that I considered too “off-piste” for a SEFI publication. I also wrestled with the inclusion of narrative that revisited a sustained period where my academic identity was under attack. I took guidance from Ellis, Adams & Bochner (2011) who refer to the need for AE researchers to be cognizant of relational ethics, to consider the danger of implicating colleagues in their narrative. Thus, this paper is perhaps ‘nor this not that’. In seeking to reconcile a desire to engage in AE, “and” to provide a paper palatable for an engineering education conference, I have perhaps fallen short in answering the “so what” question- ‘Why does (or should) your experience matter to others? Why should readers care about your issues and experiences?’ (Herrmann and Adams, 2022, 1).

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Project “Acércate a la Ingeniería”: Impact assessment and satisfaction questionnaire

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ABSTRACT

Engineering is a key discipline in today's society, as it is sustainability. Therefore, this are concepts that must be introduced in early educational levels. In this context, the project "Acércate a la Ingeniería" (Get closer to Engineering), designed and carried out by the Department of Education of the Government of the Canary Islands in collaboration with the Industrial and Civil Engineering School (EIIC) of the University of Las Palmas de Gran Canaria (ULPGC), has arisen. This project brings together eighteen secondary schools (IES) from five of the eight Canary Islands. The aim of this project is to educate students to prevent their rejection of engineering degrees by the participation in different activities that brings them closer to engineering. Various questionnaires have been carried out in order to measure the impact this experience had on said students, as well as the differences between boys and girls in engineering matters and the satisfaction level of the participating groups. This paper focuses on the results obtained from said questionnaires and their analysis.

1 INTRODUCTION

As an indispensable part of the STEAM disciplines (science, technology, engineering, arts, and maths), engineering has a leading role in society's development. However, it suffers from a lack of qualified professionals as a result of the rejection of engineering degrees by young students (Ministerio de Universidades 2022). Moreover, sustainability, inherently related to engineering, is now becoming a key concept in our planet's future. Therefore, these concepts must be introduced to young students during their academic education.

In this context, the project "*Acércate a la Ingeniería*" ("Get closer to Engineering") has arisen. Eighteen secondary schools (IES) from five of the Canary Islands, alongside with the School of Industrial and Civil Engineering (EIIC), of the University of Las Palmas de Gran Canaria (ULPGC), have participated. The aim of this project is to educate students about engineering and sustainability, using the control of invasive plant species as the general theme of the project.

To measure the impact of this experience, some questionnaires have been carried out. This paper focuses on the results found between the experimental and control groups in the initial questionnaire, as well as the differences between boys and girls answers, in order to study the existing gender gap in STEAM disciplines (Longe et al. 2019). Furthermore, the level of satisfaction of the experimental group during the visit to the Workshop "Las Cocinas" has been measure through a normalized questionnaire.

1.1 Sustainable Development Goals 2030 (SDGs)

Nowadays, sustainability has become a highly discussed topic. As a result, people are more aware than ever of the impact their actions have on our planet's environment. Students must be educated about this topic so they can take action from early ages and develop an environment-friendly mindset and lifestyle. Subsequently, this project is aligned with Sustainable Development Goals 2030 (SDGs). The following four have been the main focus:

- SDG 4 Quality Education illustrates that education enables upward socioeconomic advancement and is key to escaping poverty. In recent years, education has made great strides such as access, especially for girls.

- SDG 9 Industry, Innovation and Infrastructure focuses on the introduction of new technologies and the efficient use of resources, which goes hand in hand with inclusivity and sustainability. The introduction of digital design and manufacturing technologies, in this case, will encourage students to engage in more experiential learning.
- SDG 12 Responsible Consumption and Production is based on ensuring livelihood of current and future generations. This experience aims to contribute by showing students the possibility of generating products using sustainable plant-based or bio-composted materials.
- SDG 17 Partnerships for the Goals is achieved through the collaboration of the university with secondary schools, thus promoting learning at different educational levels.

1.2 STEAM Vocations

A lack of STEAM vocations has been detected among young (Tayebi, Gomez, and Delgado 2021; Sánchez-Martín et al. 2017), which is a cause of concern in the engineering field. Different factors, such as the believe that STEM degrees are too difficult or the absence of guidance when choosing a degree, cause students to reject engineering branches, according to studies carried out by the Spanish Association for Digitalization (2019) (Araña-Suárez 2022). Girls seem to be the ones that are more affected by this, as the belief that women face higher difficulties than men when studying STEAM degree is well established (Ng and Fergusson 2020). Some studies, that had been carried out by this research group, investigate the cause of this situation. The results obtained highlight the following aspects:

- Improving self-perception
- Generating connection with scientific-technological activities
- Generating meaningful experiences in early ages
- Increasing the number of references.

1.3 Maker Education

The maker movement brings together people known as Makers (engineers, artists, designers, and amateurs) to create and build new objects and product by embracing the concept *Do It Yourself* (DIY) (Kwon and Lee 2017). This dynamic has created new working spaces known as Makerspace, where these activities can take place. Makerspaces have arisen in universities and libraries, as well as in primary and secondary education, strengthening teamwork and fellowship among participants (Liberato et al. 2019). This has resulted in the concept of Maker Education (Martin, 2015). Through the Maker Movement and Makerspaces activities, this project has tried to encourage students to acquire STEAM vocations.

2 METHODOLOGY

2.1 Project description

This project is based on the design and implementation of a descriptive and practical experience. This experience was offered to the participant IES by the Educational Innovation Group in Manufacturing Engineering, part of the EIIC. These IES are assigned to one of three different areas, which are: Geomatics Engineering, Chemical Engineering and Industrial Chemical Engineering, and Engineering in Industrial Design and Product Development.

This paper focuses on the experience offered by the Engineering in Industrial Design and Product Development group. This professional activity has its centre of attention in products' life cycle, paying special attention to the actions taken during the design and manufacturing process of all type of products and taking sustainability into account. This includes the use of digital modelling and advanced manufacturing processes and technologies. In this experience, students received descriptive and practical information which they later made use of by designing a part. Moreover, they visited the Industrial Design Engineering Workshop called "Las Cocinas", located in the ULPGC campus. Here, students had the opportunity to acquire knowledge about various technologies, helping them comprehend the requirements for designing the part. Additionally, they were shown materials and objects based on natural fibres.

2.2 Objectives

The objectives of this project are the following:

- O1. Awaken the curiosity and interest of 4th of secondary school students in technology knowledge through workshops related to different specialties in the field of engineering.
- O2. To transmit the idea that engineering is the discipline that allows the implementation of knowledge, both scientific and technical, aimed at improving and facilitating the human being's daily life.
- O3. To bring students closer to the multidisciplinary nature of engineering.
- O4. To enable teamwork and the exchange of experiences of those centres interested in educational innovation in the field of engineering.

2.3 Phases

This project consists of five phases:

- **Phase I**. Initial meeting between the EIIC professors and the IES teachers. At this point, the initial questionnaire was shared with the IES teachers, who enabled students to fill it in. A part of this questionnaire is based on previous research (Ng and Fergusson 2020).
- **Phase II**. This phase consists of two different sessions, one at the centres and the other at "Las Cocinas". The first session is an introductory and demonstrative activity in the IES themselves taught by professors, researchers, university students and collaborators of the EIIC linked to the project. IES students are introduced to the field of design and develop new sustainable product based on the use of natural fibres from invasive species of plants. During the introductory activity, students are taught the knowledge of industrial design engineering, sustainability, invasive plants, and sustainable manufacturing of parts and tools. In the demonstrative part, students and IES teachers are shown an example of how their product will be manufactured. The second session is performed in "Las Cocinas" Workshop, where they learn first-hand about the advanced manufacturing technologies available there and perform hands-on activities. Furthermore, at the end of the workshop experience the students were asked to fill in a Course Experience Questionnaire (Wilson, Lizzio, and Ramsden 1997) to measure the level of satisfaction. A standardized questionnaire based on previous researches (Corbalan et al. 2013; Marsh, Touron, and Wheeler, n.d.).
- **Phase III**. In the third phase, the students together with the IES-teachers in their centres must design and develop a product following the requirements given. To facilitate this task, tutorials have been elaborated for IES students and their

teachers with the aim of showing them how to use a simple 3D modelling software, Tinkercad. Thus, using this software, students were asked to design a part. This part would be manufactured using resin 3D printing, followed by the creation of a mold through thermoforming, enabling the replication of the piece through gravity casting.

- **Phase IV.** In the fourth phase, each centre was asked to present their projects at the EIIC with the aim of sharing what they have learned. Moreover, the students were asked to fill in the final questionnaire. The comparison between the initial and final questionnaire allows an impact assessment study.
- **Phase V.** A final report, which presents the results obtained, is completed and submitted for each school.

3 RESULTS

This paper focuses on the results obtained in the initial questionnaire, filled in by 4º ESO students at the beginning of the project. The students who participated in this project are those who belong to the selected IES and are taking the Technology subject. This group is denominated the Experimental Group (EG). A group of students who have not participated on this project also filled in the questionnaire. This one is denominated the Control Group (CG).

The questionnaire is divided into two parts. The first one asks about basic information (IES name and student's gender). The second one is based on the Likert Scale, which shows the level of agreement and disagreement students have with the statements shown in **Table 1**.

Table 1. Statements of question number 4 of the initial questionnaire

p1	I'm aware about the climate change.
p2	The term sustainability is familiar to me.
p3	In my daily life, I take action to contribute to the creation of a more sustainable world.
p4	I believe that engineering can make the world more sustainable.
p5	If I learn engineering, I will be able to improve things that people use every day.
p6	I am good at building and fixing things.
p7	I would like to use creativity and innovation in my future job.
p8	Knowing how to use mathematics and science together will allow me to invent useful things.
p9	I would like to pursue a university degree.
p10	I believe I can be successful in an engineering career.
p11	I am interested in learning more about industrial design engineering.
p12	I am interested in learning more about chemical and industrial chemistry engineering.
p13	I am interested in learning more about geomatics engineering.

In the first 3 questions, which are generic and refer to the terms of sustainability and climate change, there is almost no difference between groups and genders. It was observed that all students were aware of these terms, as they have been mentioned before in the classroom. Mostly students indicated their familiarity with these terms when asked about them, but they were not capable of providing an exact definition. This was observed by the collaborators when visiting the IES.

Question p4 addresses engineering's capacity to enhance sustainability. A notable difference was found between the EG and CG. Over 80% of EG students believe that engineering can contribute to making the world more sustainable. In contrast, the percentage is lower within the CG.

Similarly, in p5 *"If I learn engineering, I will be able to improve things that people use every day"*, more than 80% of EG students answered with either *"agree"* or *"strongly agree"*. Moreover, after the session in the IES, many students show a better understanding of the role that engineering plays in society. However, the percentages are lower in the CG, with approximately 70% of CG girls and 65% of CG boys expressing agreement.

Question p6 asks about the students' perception of their abilities to build and fix things. A difference is clearly seen between EG girls and CG girls. 43% of EG girls answered *"strongly disagree"* or *"disagree"* while 62% of CG girls answered the same. Therefore, a higher percentage of EG female students believe they are good at building and fixing things when compared to the other groups. They are followed by EG boys, CG boys, and lastly CG girls.

A significant difference between the EG and CG is observed in question 7. Over 80% of EG students would like to use creativity and innovation in their future job. Nonetheless, in the CG that percentage is lower, particularly among male students (58%). These results seem to indicate that students who study technology are significantly more interested in topics related to creativity and innovation than those who study other subjects.

Question p8 focuses on the usefulness of combining knowledge of mathematics and science in order to invent useful things. Approximately 75% of CG students, both boys and girls answered *"agree"* or *"strongly agree"*. However, a slight difference was observed in the EG between genders. Female students considered mathematics and science more useful (85%) than male students (77%).

Regarding the desirability of pursuing a university degree (p9), the results are aligned with the current national data on education (Ministerio de Educación y Formación Profesional 2021). In both, EG and CG, it is observed that more than 80% of girls wish to pursue a university degree. On the other hand, 15% of EG boys answered *"strongly disagree"* while this percentage increases to 30% with CG boys.

In question p10, the possibility of success in an engineering career is explored. Both genders of EG students answered more positively than CG students. However, when comparing question p6 and p10, it is observed that EG girls think they could be successful in a smaller proportion, although they had previously stablished their capacity to build and fix things. This seems to suggest that girls do not tend to associate these abilities with engineering degrees, which reflects the existing lack of STEAM vocations in the female students.

As to students' interest in the different engineering branches which participated in the project, EG chose Design as their first option, followed by Chemistry and lastly Geomatics. CG chose Chemistry, Design and lastly Geomatics. All these results are shown in **Fig. 1.**

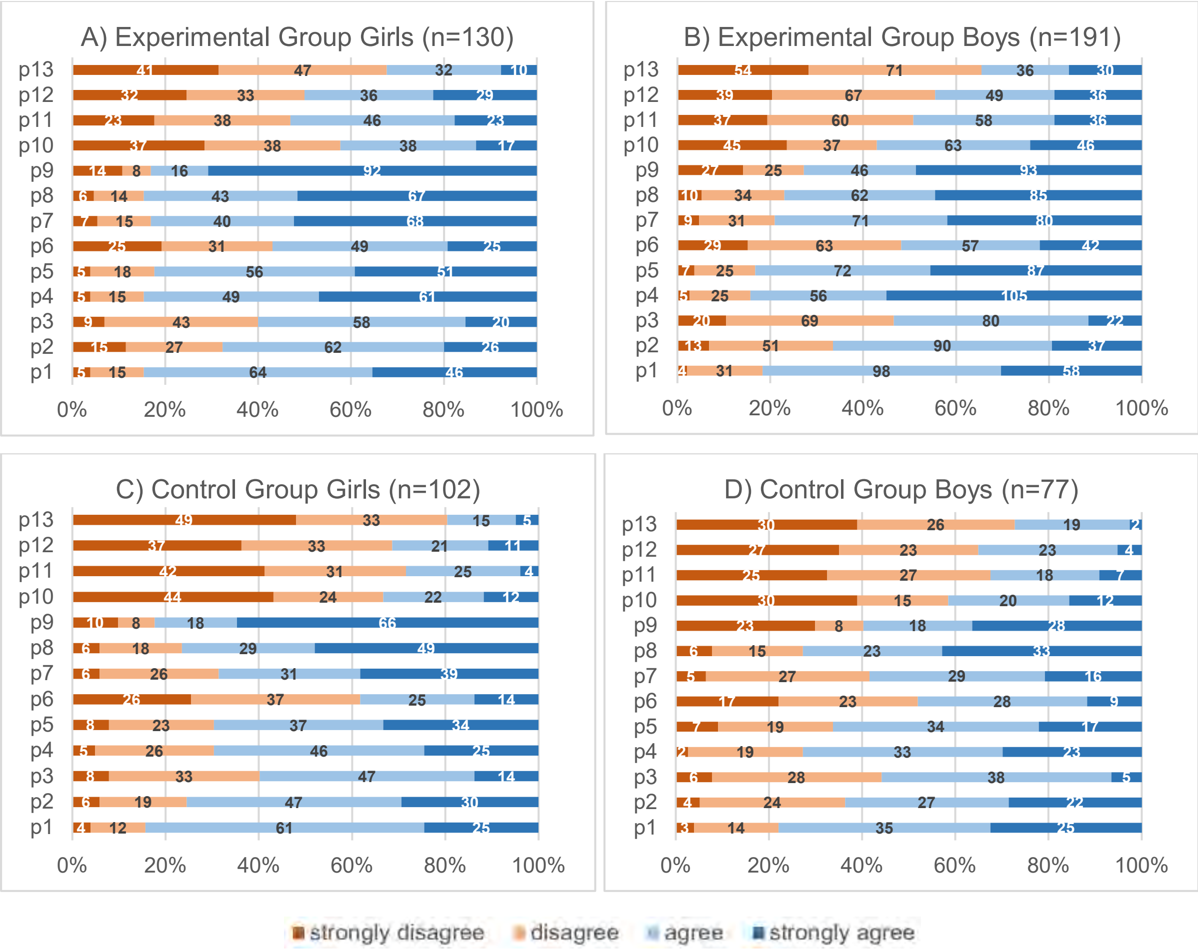

Fig. 1. Statements of question number 4 of the initial questionnaire.

The results obtained in “Las Cocinas” Workshop Experience Standardised Questionnaire are shown below in **Table 2**. Statements are arranged based on their average score (5 being the highest score possible).

Table 2. “Las Cocinas” Workshop Experience Standardised Questionnaire [CEQ]

Order	Statement	Average score
7	The activity was well organised.	4,49
6	The activity provided me with a wide perception of technology.	4,28
13	My participation in the activity was worth it.	4,26
20	The material provided during the activity was relevant and up to date.	4.24
19	The material provided during the activity was precise.	4,22
21	The information and communication technology used during the activity was effective.	4,21
14	I felt I was part of a group of students and staff committed to learning.	4,16
9	The activity was flexible enough for it to adapt to my needs.	4,13
10	I found the activity intellectually stimulating.	4,09
8	The activity's content was systematically organized.	4,08

17	Ideas and suggestions made by students were listened to and used during the activity.	4,08
1	The activity encouraged my enthusiasm for learning.	3,99
18	Available resources to help me learn were mentioned.	3,98
12	I found the activity motivating.	3,95
4	The activity developed my confidence to investigate new ideas.	3,86
15	I was able to explore my academic interests with students and staff.	3,86
2	My experience during the activity has encouraged me to value points of view different to mine.	3,79
16	I learned to confidently explore ideas with other people.	3,78
11	The activity has stimulated my interest about the topic.	3,74
5	I consider what I have learned to be valuable for my future.	3,72
3	I learned to apply the principles of this activity to new situations.	3,58

As shown in **Fig. 2**, it is remarkable the positive evaluation of the visit to "Las Cocinas" Workshop received, being approximately over 90% of answers *"strongly agree"*, *"agree"* or *"neutral"* in all statements. It is worth mentioning that statement number 7 *"The activity was well organised"* received a 67% of *"strongly agree"* answers and none *"strongly disagree"* answers. From the point of view of EIIC collaborators, who adapted the activity in accordance with each group's characteristics and needs, as well as the available time, it is remarkable that students perceived that the activity was well organised.

Furthermore, statement number 6 *"The activity provided me with a wide perception of technology"*, 85% of answers were *"strongly agree"* and *"agree"*, and none *"strongly disagree".*

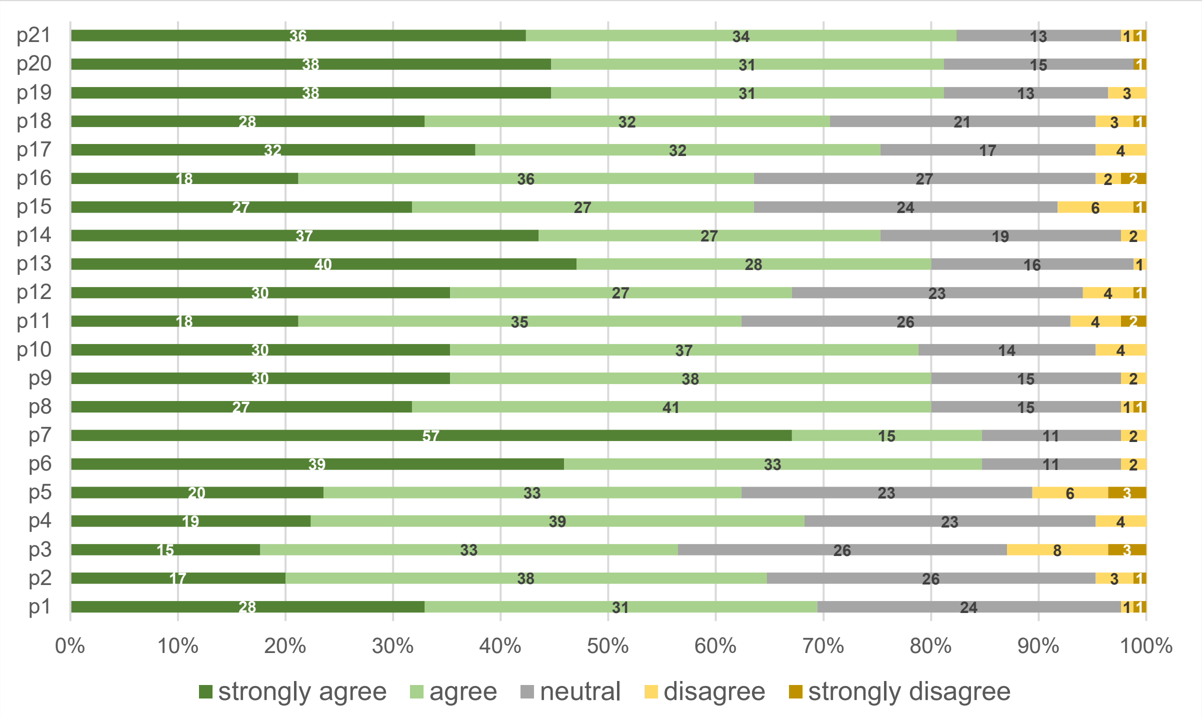

Fig. 2. "Las Cocinas" Workshop Experience Standardised Questionnaire [CEQ].

Once the project ended, it was observed that students of both genders showed a better comprehending of sustainability in the first three questions. Moreover, those questions focused on engineering, like p5, p7 or p10, indicated slightly fewer positive results. This may be attributed to the fact that, upon gaining a better understanding of what engineering entails, they become aware of its complexity. Thus, students perceive themselves as less capable of tackling it compared to their initial perceptions. However, during the visits made by students, it was observed that they indicated a higher interest in engineering degrees and saw them as a possible option to choose after high school, especially female students.

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INCLUSIVE DESIGN IN ACTION – A CASE STUDY DESCRIBING THE DESIGN OF SOCIAL AREA SEATING IN A UNIVERSITY

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ABSTRACT

This practice paper outlines the inclusive design process used in the redesign of communal/social seating in an Engineering faculty in a University in Ireland. The old seating was not being utilised by the students. Engineering courses often present challenging assignments to students; literature shows that access to information, knowledge exchanges and opportunities for learning through social interaction can be crucial to student success.

Equality, Diversity, and Inclusion (EDI) has grown as an important agenda item across society. Therefore, the methodology used in this redesign was inclusive design. Inclusive design is a design framework that takes into account the diversity of the human race and embraces co-design to ensure no one is excluded. It is "…not

designing one product for all people; instead, it's designing a diversity of ways to participate so that everyone has a sense of belonging"(Holmes 2018).

The design team on this project was composed of a voluntary, diverse group of students and staff. The data collection methods employed was a design walk through of the University, a faculty-wide survey, and a design hackathon.

The inclusive design process resulted in various social seating designs that addressed the needs of a broad range of users, including those with physical disabilities and sensory impairments. The final designs are available for perusal in Appendix 2, that show a more inclusive space for students and staff to interact and collaborate.

The findings of this study highlight the importance of using an inclusive design process when designing academic environments. By involving a diverse group of stakeholders in the design process, the resulting spaces can better cater to the needs of all users. The recommendation is for other higher education institutions to consider implementing inclusive design principles in their design processes to ensure all members of their community are catered for, leading to a more inclusive and accessible academic environment for all.

1. INTRODUCTION

This practice paper describes the inclusive design process that was implemented during the updating of the communal seating areas in Atlantic Technological University (ATU) Sligo's Engineering block. The process has been documented as it showcases inclusive design in action. The Commission for Architecture and the Built Environment (CABE 2023), the advisor to the UK government on architecture, urban design, and public space, describes inclusive design as a design framework that "aims to remove the barriers that create undue effort and separation. It enables everyone to participate equally, confidently, and independently in everyday activities". Research shows that students learn most when they study in informal settings like cafeterias, dormitories, student unions (Hunter and Cox 2014; Matthews, Andrews, and Adams 2011; Bennett 2007; Terenzini, Pascarella, and Blimling 1996).

The original seating in the Engineering block was not utilised by students as a social space. Feedback gathered on the seating through a survey stated that the area was uncomfortable and badly lit, with unsuitable tables and with no charging technology or wheelchair access. Therefore, the purpose of the redesign was to create seating that would consider all the needs of the diverse population of the University. The volunteers on the diverse project design team consisted of lecturers, administrative staff, technicians, and students, including those differently abled and disabled. The team was supported by the university's disabilities experts and facilities staff at every decision point. Using Microsoft's cycle of exclusion framework (Microsoft n.d.) , which is based on the principles of inclusive design, the redesign process ensured that the diverse population's needs were accounted for. As described by Treviranus (2018), founder of the Inclusive Design research centre (IRDC) in Canada, the challenge of implementing successful inclusive design within products and environments is to maintain a unified aesthetic while adding affordances for difference.

Section 2 of the paper describes the principles of inclusive design and Microsoft's cycle of exclusion. Section 3 summarises the literature review findings on the importance of communal or social seating in an educational environment. Section 4 outlines the methodology used in the redesign process, including details on the design hackathon, and supporting surveys. The results from the data gathered is outlined in section 5. Section 5 also gives the final designs for the seating areas.

It is hoped that this research can inform others on inclusive design and how it can be implemented though use of a diverse team and a co-design process.

2. INCLUSIVE DESIGN

The over-arching methodology employed by the social seating project was that of Inclusive design. Inclusive design grew out of the Universal Design movement, and places emphasis on inclusion and adaptation of education systems to individual differences (Gordon and O'Leary 2015). Inclusive design is “a methodology that enables and draws on the full range of human diversity. Most importantly, this means including and learning from people with a range of perspectives”(Microsoft n.d.). In this design methodology, diversity embraces all human differences, including ability, language, culture, gender, and age. This definition by Kat Holmes, while she worked at Microsoft, is expanded upon in her book titled ‘Mismatch’. In that, she describes inclusive design as not designing one product for all people; instead, it’s designing a diversity of ways to participate so that everyone has a sense of belonging (Holmes 2018). For the seating project, this meant that the design team were not trying to have one seat design intended to serve as many needs as possible. Instead, the team created multiple designs – each optimised for the identified needs of a subset of the university’s population. In keeping with the advice of the Canadian IRDC, all designs maintained a unified aesthetic (Treviranus 2018).

This project used the guiding framework for inclusive design, developed by the Inclusive Design Research Centre (IRDC) in Canada (Treviranus 2018). The three dimensions of the framework are:

1. Recognise, respect, and design with human uniqueness and variability.

2. Use inclusive, open and transparent processes, and co-design with people who have a diversity of perspectives, including people who can’t use or have difficulty using the current designs.

3. Realise that you are designing in a complex adaptive system.

Society has embraced a version of a ‘normal’ human being, one based on averages of data gathered on a tiny subset of humanity (Quetelet 1969), to allow for a single engineered solution to designing environments, products and services. Inclusive design eradicates this notion of a typical, average or so called ‘traditional’ student (Kelly 2017). This is why the three dimensions of the IRDC framework are not a set of static structures that explain how to engineer an inclusive solution, simply because current society does not allow for such a process without excluding portions of society. Inclusive design takes an alternate approach in that one designs for diversity, for the ‘vital few’ 20% on the outer regions of the normal distribution curve (Harvey and Sotardi 2018) as illustrated in Figure 1.

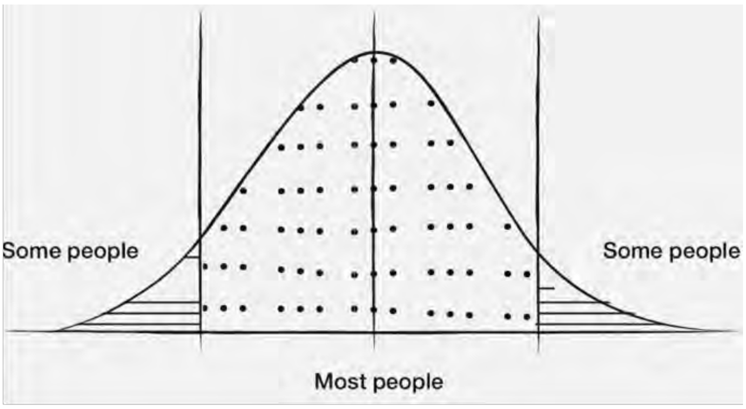


Figure 1. A normal distribution curve of the similarity between people(Harvey and Sotardi 2018)

Inclusive design is not achieved with separate designs; instead, it is achieved through the process of understanding the needs of our diverse world and incorporating them into the design brief. Ironically, by not solely designing for the middle segment, (the 80%), the product ends up being as easy to sell to that population as design for the 'normal' human being, while also reaching other audience segments, 'the vital' few 20% (Holmes 2018).

Microsoft built upon the 3 principles of inclusive design by considering who was being excluded with any given design. As Holmes (2018) stated, exclusion is only truly understood when it is lived. For this reason, the feedback gathered on the old seating in the Engineering block was of vital importance and was used to inform the first iteration of the new designs. The cycle of exclusion is illustrated in Figure 2 below.

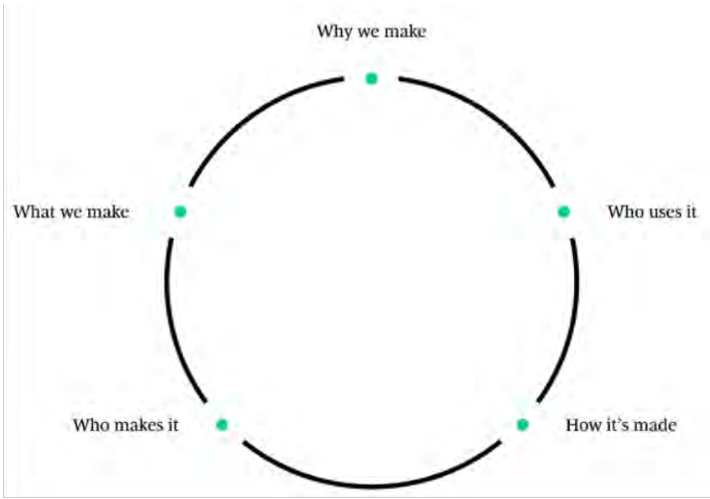


Figure 2. Microsoft's cycle of Exclusion(Microsoft n.d.)

Cultural context and pre-existing designs can perpetuate the cycle of exclusion. The designer holds the power to determine who is and is not able to participate in the new environment/product/service being designed (Holmes 2018). This knowledge was the rationale behind the diverse design team of both students and staff involved in this redesign project, as a diverse team offers the necessary voices on needs requirements, thereby ensuring less exclusion.

3. COMMUNAL/SOCIAL SEATING IN EDUCATION

Equality, Diversity, and Inclusion (EDI) has grown as an important agenda item across the Third level education sector. Research has suggested that the design of our learning spaces should become a physical representation of the institution's vision and strategy for learning – responsive, inclusive, and supportive of attainment by all (JISC 2006).

Aligning with the normal distribution representation given in Figure 1 above, the design team concluded that 'Most people' in ATU Sligo are able-bodied, neurotypical students and staff. In addition, 'Some People' are neurodiverse, and "Some People' are differently abled and disabled. The strength of inclusive design is that by focusing on the needs of the population on the outer sections, the inner 'Most people' are then naturally incorporated into the design.

Therefore, understanding the needs of both neurodiverse, differently abled and disabled was crucial for avoiding exclusion and creating enhanced learning and working environments for all. The following section draws on current literature that details the essential aspects of learning spaces, including the physical environment.

3. 1 Learning Spaces

To ensure that students and staff succeed in an academic environment, they must be provided with the necessary tools. This should include shared areas around the campus where they can meet to work or relax. Learning can be enhanced by making social seating spaces available that are attractive to just spend time in (Strange and Banning 2001) exploring new relationships and strengthening existing ones. In addition social seating can encourage learning through dialogue, problem-solving, information sharing and even studying alone in a supportive atmosphere (JISC 2006).

Collaboration, group work, project work and lecturer feedback are all important parts of an Engineering Faculty and can contribute to developing a sense of community among students (Amarathunge and Madhuwanthi 2020). Studies have shown this persistent sense of community results in higher academic performance with self-empowerment (Kuh 2001). In addition, learning results from interactions, whether they be with aspects of the environment, information, other people, or through some combination of these (AJ. 2007). Social seating areas help to increase this interaction, collaboration, and social engagement among students through multiple processes (Jamieson et al. 2000).

Seating areas and other public areas around campus also often provide social capital, where social capital is defined as the information, resources and opportunities derived from social interactions (Lin 2002). Importantly, studies have shown that the difficulties associated with Engineering courses foster a need for students to access social capital (Seymour, Hunter, and Harper 2019). Because well-designed communal seating enables collaboration, personalisation, flexibility, and inclusion (JISC 2006), it can provide students with access and the ability to obtain this social capital, to overcome some of the difficulties they may face and enhance their overall education experience.

3.2 Physical Environment Considerations for Inclusion

ATU Sligo became the first autism-friendly Technological University in December 2022. The work of Dr Magda Mostafa, developer of the Autism Friendly University Design Guide in 2021, has been used to inform ATU (Mostafa 2021). The Autism Friendly University Design Guide has a focus on the built environment, supports, strategies and guidelines to achieve an autism friendly university. "Research has shown that the architectural environment can play a conducive role in the facilitation of inclusion and support of access for autistic individuals, particularly in learning environments"(Mostafa 2008, 2021). Sensory barriers that were identified in The Autism Friendly University Design guide (Mostafa 2021)were as follows:

- Acoustics
- Color
- Texture and Materiality
- Lighting
- Smell

Several barriers to those with autism were also identified In *Living with Autism as a University Student at Dublin City University: Developing an Autism Friendly University report (Sweeney et al. 2019)*. The barriers most relevant to the social seating project were:

- Having heightened sensory awareness of noise, bustling environments, smells, and lighting
- Bright colours like red on walls and fluorescent lighting
- Hard seating surface
- Dimly lit spaces
- High noise levels in eating areas such as canteens

To ensure inclusion for those disabled, measurements around the seating areas of interest were taken. A wheelchair user took the design team on a tour of the Engineering faculty and explained the access issues that needed to be avoided. Examples included desk heights, closed-in spaces/booth type designs, platform for seating and power access in hard-to-reach areas.

4. METHODOLOGY

The methodology used for the seating project was qualitative. The first data collection method used was a design walk through with the diverse design team. Measurements were taken of the seating areas, and access issues were discussed. Second, a survey of all Engineering students and staff in the Engineering faculty was taken. Following this, a lecture was given to all members on inclusive design, and then finally, a design hackathon was used to get input into the end designs of the seating.

A qualitative study was chosen as it was the lived experiences, the observations from the hackathon and the survey that could make the most contribution to the new designs. The following sections briefly discusses the survey and the Hackathon.

4.1 Hackathon

Hackathons are short-term and intense events where diverse groups gather to solve a defined problem (Heller et al. 2023). Design Thinking was the strategic and practical approach taken to the design hackathon for the social seating. Design thinking emerged from the design philosophy and practice at Stanford in the Hasso Platter Institute of Design, known as the d.school. Design thinking is a humanistic approach to design which facilitates creativity and innovation. It translates problems and needs into design with people at the centre. It provides a framework which gives people the confidence to collaborate to solve problems (Auernhammer and Roth 2021).There are five phases: Empathise, Define, Ideate, Prototype and Test. Design thinking has a shared history with "Wicked problems", a term coined by Horst Rittel to describe complex problems whose solutions are not right or wrong.
The hackathon itself consisted of 8 people, separated into two teams of four. Each team was asked to complete 3 tasks that would get them to think about inclusive design and solving design issues.The tasks were:

1. Design an ideal seating area for your Team members (increased communication and understanding others needs)
2. 'Finding the Essence' - this involved teams listing goals and insights for the social seating
3. Design the Engineering seating areas that meeting their teams needs.

The outputs from the Hackathon are given in Appendix 2.

4.2 Survey

A survey of the wider Engineering faculty was taken so that input from all Engineering students and staff was considered as part of the design. The survey, consisting of 5 open ended questions and 3 closed ended questions, was distributed using Microsoft Forms to 1,577 suitable respondents. The areas of question were: are people currently using the Engineering section for seating; if so, then what are they using it for, what was missing, what they would like to see and how important the seating area was for certain functions in their learning and professional life. A copy of the survey is available in Appendix 1. NVivo was then used to analyse the results. The open-ended questions in the survey were first grouped to answer the topics that the results section will focus on.
One team member coded the categories from the survey questions using open coding (Corbin and Strauss 1990). A list of subcategories was created that emerged from the data. Using open coding, each term was allocated to a particular subcategory and then compared for similarities or differences. For example, coding the question that referred to preferred seating resulted in known social seating area answers such as 'Student Union' or 'D Block' added to the Subcategory called 'Social Seating'. The subcategories were viewed by other team members and after some further iterations and catergorisation the results were determined. The resulting codebook can be viewed in Appendix 3.

5. RESULTS

5.1 Participant Information

There were 43 responses to the survey. There was an equal response from people who used and who did not use the seating area in Engineering. All participants had several suggestions on what improvements could be made to make the area more inviting and usable. The observations from the survey are discussed in section 5.2.

There were 8 participants in the Design Hackathon who volunteered from a request sent to the Engineering Faculty. A summary of these participants is given in Table 1. The observations from the hackathon are discussed in section 5.3.

Participant	Area of Study	HA Team
HA Student 1	Computing year 1	Team 1
HA Student 2	Computing year 2	Team 1
HA Staff 1	Lecturer - Mechanical	Team 1
HA Staff 5	Estates	Team 1
HA Student 3	Civil Engineering year 3	Team 2
HA Staff 2	Lecturer - Computing	Team 2
HA Staff 3	Administrative	Team 2
HA Staff 4	Technician – Engineering Technology	Team 2

Table 1: Hackathon participant information

5.2 Survey results

This section is structured into the main topics the survey focused on:

1. Usage of the Engineering Section
2. Other University Seating Area preferences
3. Suggestions for improving seating area in Engineering

5.2.1 Usage of Engineering Section

Survey Participants were almost evenly split between those who used the seating area and those you did not.

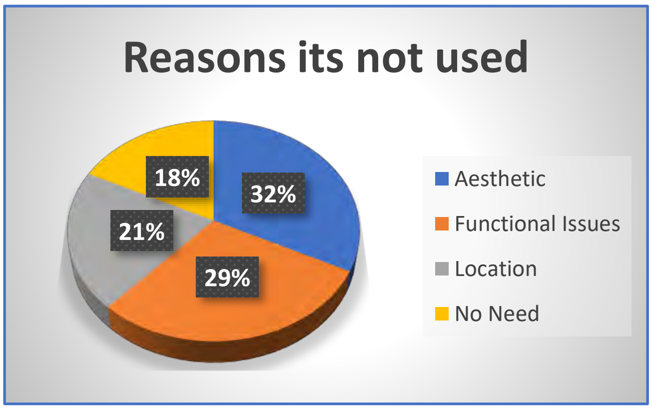


Figure 3: Reasons the seating in Engineering is not used

The majority did not use the seating because of aesthetic and functional reasons citing uncomfortable and uninviting seating, bad lighting, lack of charge points or tables as well as issues with heat, cold and draughts.

Concerns were also raised about the location of the seating being too far from food facilities and in busy areas. Interestingly, a minority of participants indicated that they had no need for social seating as they went home when classes were over.

5.2.2 Other University seating area preferences

When asked about their preferences for communal seating throughout the university, most participants preferred private and quieter areas in the college or the busier canteen and social areas suitable for meeting people.

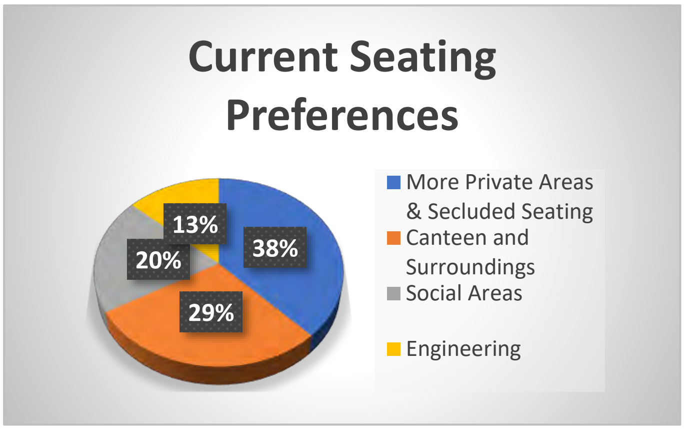


Figure 4: Preferred Seating areas in university

Interestingly, while 23 respondents said they used the seating in the Engineering area only 6 participants mentioned it as a preference. All 6 participants listed the 2nd floor as their preferred location in the Engineering area.

When asked about their requirements for communal seating, most respondents (52%) liked communal seating areas because it provided them with a space to do group and individual project work. Some preferred spaces that were quiet, whiles others liked meeting new people. Participants also mentioned comfortable seats with partitions that blocked sound and reduced anxiety as a requirement for a preferred seating area. One respondent described how different areas on the college are preferred for different reasons.

“The area outside the library provides private spaces but lacks access to monitors and power sockets. The social learning area beside the coffee dock in the D block provides access to power sockets and monitors but lacks privacy.”

Respondents also preferred certain areas due to their location and what it allowed them to do, such as proximity to labs, central to the campus, to use laptop and tables for food or books. Surprisingly, only 2 of the participants that preferred the canteen mentioned the closeness to food/coffee as the reason. To a lesser extent, participants stated that areas should be well lit, warm and colourful.

5.2.3 Suggestions for improving seating in Engineering

When asked for change or input on the current seating area, the majority of participants want a change to the seats themselves (62%), and the addition of heat, power and light to the areas (29%). With regards to the seats, feedback on requirements from the participants was as follows:

“More comfortable seating - the wooden bench type design currently is hard to sit on for over 10 mins, the walls are painful after a period also as you lose heat directly from your back if you lean back”.

"At the moment you slide off the bench and if you're using a computer, you're having to learn forward over the table in order to be comfortable at all using it an elevated table and some separate seating I think would improve the area."

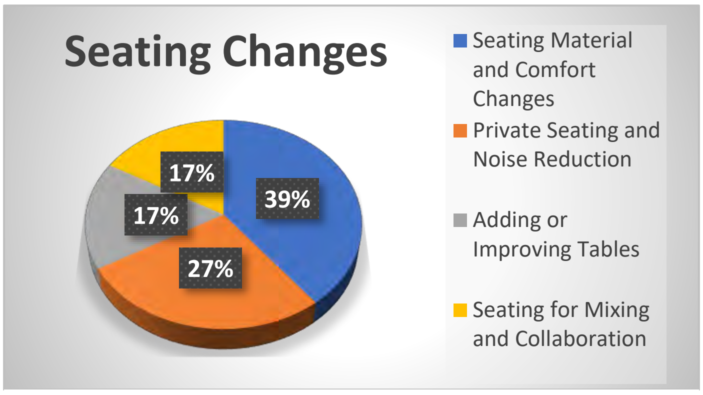


Figure 5:Recommended Seating Changes

With regards to the seating(Figure 5), participants requested an improvement to its comfort with softer, padded seating material and the addition of back support.

Following this, participants requested making seating more private, reduce noise or creating a division between traffic. This contrasts with the participants that state meeting people and casual discussions are more important for seating areas (**Error! Reference source not found.**).

A student that disclosed their autism described how private secluded seating reduced their anxiety, and other respondents mentioned they liked privacy for studying, calls and to reduced distractions.

Respondents also suggested improving the social aspects of the seating, changing the seating type to catalyse collaboration, meeting people, discussion, and project work.

"I use the canteen but would like an area within Engineering where you could meet others within the department."

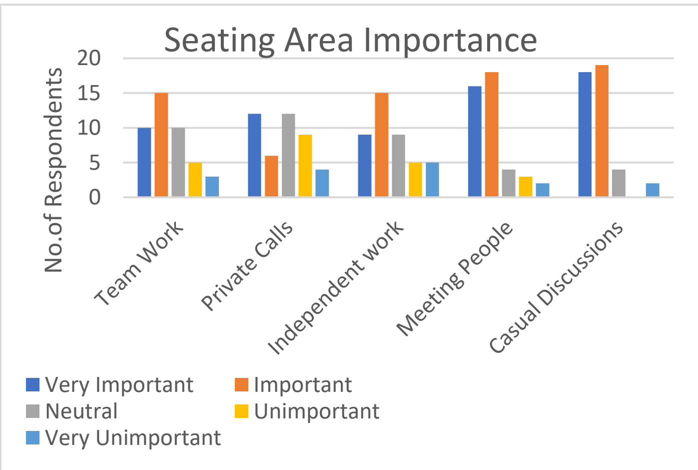


Figure 6: Importance of seating area functions

The respondents also indicated the importance of tables at seating areas with references to the lack of tables or incorrect table height. There were also suggestions to elevate tables, add tables for laptop and books, add tables to support wheelchair users and add more tables.

"Tables located at some chairs at the correct level for coffee, eating, laptop and wheelchair users."

"An area to use laptops would be ideal since we have plenty of projects that need software, so we need an area to do it outside of the lecture rooms".

There were also frequent recommendations to add heat (13%), power (35%), and light (52%).

5.3 Hackathon results

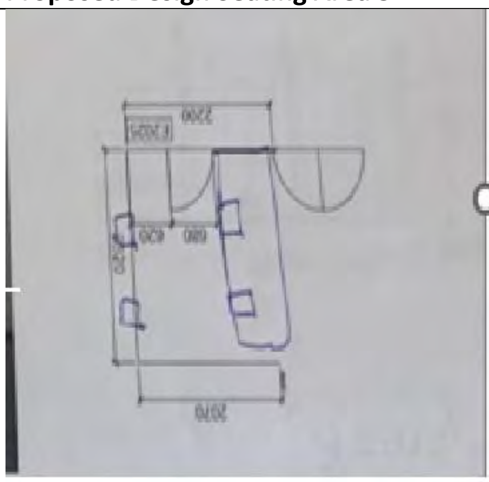
The hackathon provided a place for the participants to express their voice on what was important to them so that their communal seating needs could be understood. Team 1's needs included "Wheelchair Accessible", "Acoustics – quiet area, not echoey", "Comfortable seats" while Team 2 prioritised "Comfort - less Wooden Benches", "Tables at correct height" and "Brighter Colours".

Following this, the teams were asked for their inputs on why the old seating areas were not used and their goals for the new areas (Table 2).

Team	Goals	Insights
Team 1	Student wise: Respite and a workspace for projects	Currently very dark. It seems like a transition place that students leave to go elsewhere.
Team 2	Staff wise: Place became alive/ more use by students and a place to give student feedback.	Students don't feel like they belong there.

Table 2: Hackathon goals and insights for seating area

The overall output from the hackathon event were several Images and descriptions (Appendix 2) on suggested designs for the various social seating areas in the Engineering block. An example of the proposed seating for two of the areas are given in **Error! Reference source not found.**. The full set of designs that the teams illustrated or suggested are in Appendix 2 and was one of the main contributories to the final design proposal.

Team	Current Area 5	Proposed Design Seating Area 5
Team 1		

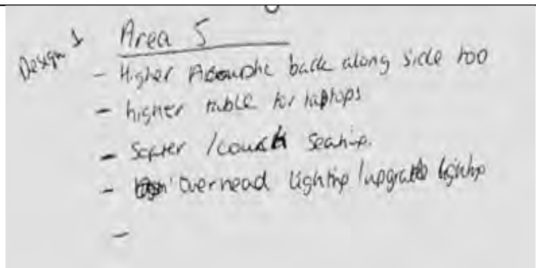
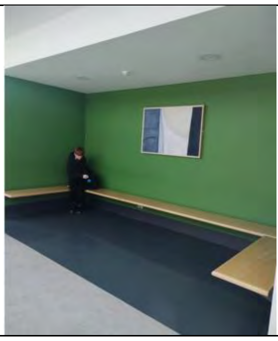
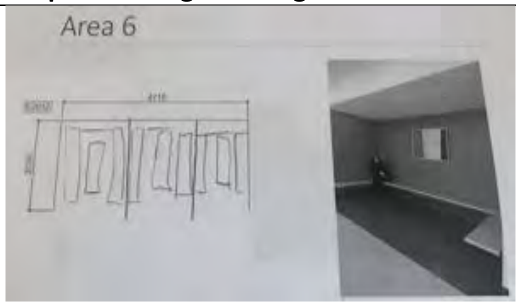
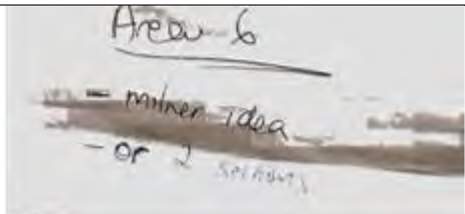
Team 2		
	Current Area 6	**Proposed Design Seating Area 6**
Team 1		
Team 2		

Table 3:Suggest Design for two Seating areas

5.4 Overall Results Conclusion

The literature review, design walk through, the survey and the hackathon results highlighted several areas that should be included in the design proposals. By implementing the inclusive design framework, and being aware of the cycle of exclusion, the needs of all the Engineering faculty were considered.

Underpinned by the findings in the Autism Friendly University Design guide and informed by the disability office and the lecture on inclusive design, both the survey and the hackathon were used to complete the final seating designs.

The Engineering Faculty seating is distributed over three floors. The design of the seating would be an iterative process, designing one floor at a time and using the feedback to further improve designs of other areas. This is to ensure we meet the 3rd principle of inclusive design that recognises any design is part of a complex adaptive system. Therefore 5 areas in total were designed in this iteration, with each of the areas being on the second floor of the Engineering building as the 2nd floor was the one most referenced in preferred seating areas in the survey.

Using the same two examples given in the hackathon results (Namely areas 5 and 6), the final design was as follows:

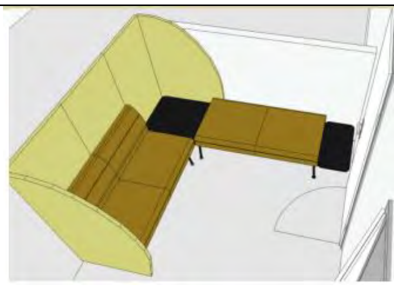
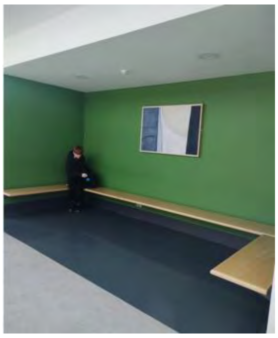
Area	**Proposal**
Area 5  	 **Proposal Description:** L-Shape sofa comprising 2 seats and 2 cushions, 1 large table elements and 1 small adjustable table element. SIZE : 2305 x 2010. Surround screens. 1310 mm High. 3 rectangular and 2 curved end. Selected fabric Charge outlets in tables: 2 USB charger (5V/DC 2,1A) with BS Plug
Area 6 	 4-person booth with screens. Cabin with visual and acoustic protection for a maximum of 4 users. Table with painted base and melamine top. Black painted legs Charge outlets in tables: 2 USB charger (5V/DC 2,1A) with BS Plug Acoustic wall panel 2000 x 1100. Eclipse COSY Light. 8W LED. Desk through fix 68cm High with white shade

Table 4: Design Proposals for Areas 5 and 6

Area 5 above is open to the main corridor, so the side screen is for a little privacy and some noise reduction. This space is suitable for group work, social gatherings, student/staff feedback etc. This space is wheelchair accessible and in close proximity to a lift. The table for this area is adjustable and has the power points placed on it for ease of access.

Area 6 targets those that prefer privacy. It is designed to help reduce anxiety with extra lighting and power. Seating is much softer, as hard seats are listed as a barrier to autistic people. This private area could also provide respite to other differently abled members of the faculty (Santiago 2020).

The final design for all 5 areas is given in Appendix 2.

6. SUMMARY

This study utilised an inclusive design approach that involved a hackathon and a survey to develop a proposal for the renovation of social seating areas in the Engineering Faculty of a University. The goal of this approach was to create a more inclusive and welcoming environment that caters for the needs and preferences of diverse users. The project was guided by the inclusive design framework, which indicates that in providing for the 'vital few', you provide for the needs of all.

The proposal addressed several issues identified in the existing social seating areas, such as limited seating options, uncomfortable and hard seating, inadequate lighting and charging capabilities. By incorporating inclusive design principles, such as recognising variability and co-designing into the design of the new social seating areas, a more user-friendly and accessible space was created.

The proposed design includes a variety of seating options, comfortable textures, adjustable lighting and charging capabilities, as well as features to reduce noise such as acoustic panels and tables and seating that can include wheelchair users. These features make the social seating areas more welcoming and accessible for users with different abilities and preferences. It should be noted that it was not one design that was placed in each of the 5 areas. Instead, each area was optimised for a particular cohort of students and staff, while ensuring that all areas have a similar look and feel.

This study demonstrates the importance of adopting an inclusive design approach that considers the needs and perspectives of diverse users in the design of social spaces. The proposed design can inspire other universities and institutions seeking to create more inclusive and user-friendly environments.

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APPENDIX 1: SURVEY QUESTIONS

1.Do you currently use the seating in the Engineering Block?

2. Why do you not use the seating in the Engineering Block?

(Only for people who answered 1 above)

3. If there was anything you would change about the current seating area, what would it be?

4. Can you please rate the current Engineering seating areas on each of the following:
(This refers to the leisure seating area in the corridors)

	Excellent	Good	Average	Not Good	Poor
Lighting	○	○	○	○	○
Comfort	○	○	○	○	○
Usable	○	○	○	○	○
Privacy	○	○	○	○	○

5. Have you any further input you would like to make on the seating Area in Engineering?

6. Where is your current preferred seating area in the college?

7. Why do you like that area?

8. Can you please rate how important a public seating area is to you for the following functions:

	Very Important	Important	Neutral	UnImportant	Very Unimportant
Team Work	○	○	○	○	○
Private Calls	○	○	○	○	○
Independent Work	○	○	○	○	○
Meeting People	○	○	○	○	○
Casual Discussions	○	○	○	○	○

APPENDIX 2: DESIGN PROPOSAL FOR SEATING AREAS WITH HACKATHON IDEAS

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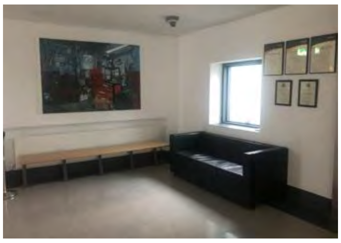
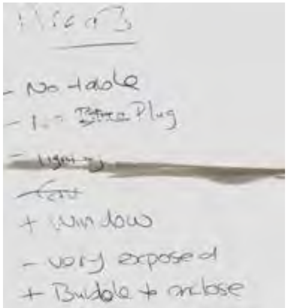
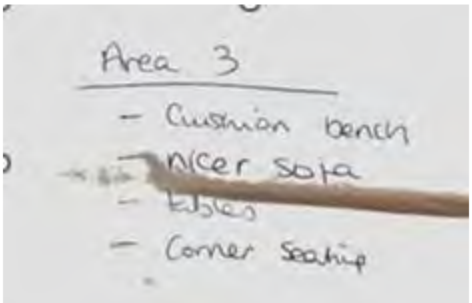
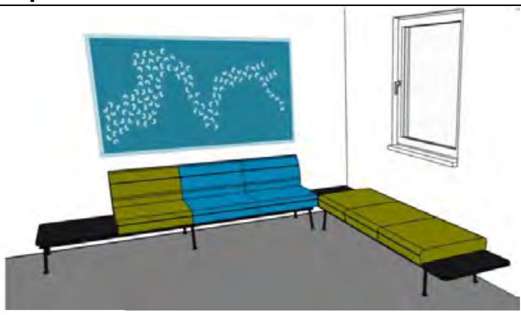
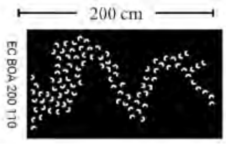


Hackathon Ideas:


</td>
<td>
  
Proposal description:
L-Shape sofa comprising 3 seats and 3 cushions, 2 large table elements and one small adjustable table element. SIZE :3250 x 2925mm.

Charge outlets in tables: 2 USB charger (5V/DC 2,1A) with BS Plug

Acoustic wall panel 2000 x 1100. Eclipse

COSY Light. 8W LED. Desk through fix 68cm High with white shade</td></tr>
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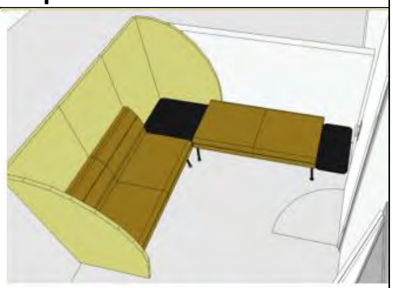
</td><td></td></tr>
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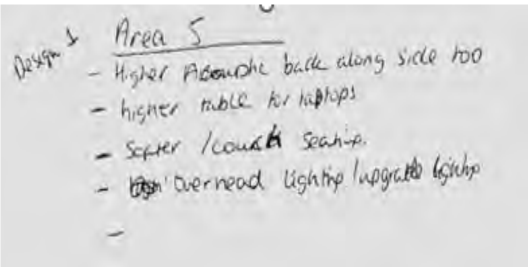
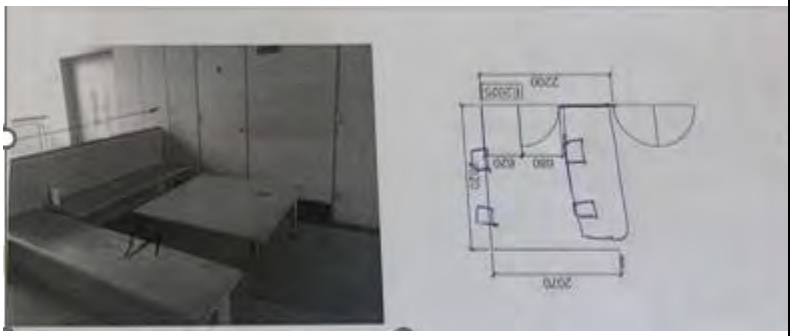
Hackathon Ideas:





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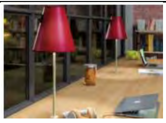

Proposal Description:
L-Shape sofa comprising 2 seats and 2 cushions, 1 large table elements and 1 small adjustable table element. SIZE : 2305 x 2010.

Surround screens. 1310 mm High. 3 rectangular and 2 curved end. Selected fabric

Charge outlets in tables: 2 USB charger (5V/DC 2,1A) with BS Plug

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<tr>
<th>Area</th>
<th>Proposal</th>
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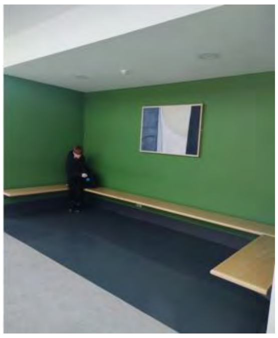
Area 6



Hackathon Sketches:

</td>
<td>

4 person booth with screens. Cabin with visual and acoustic protection for a maximum of 4 users. Table with painted base and melamine top. Black painted legs

Charge outlets in tables: 2 USB charger (5V/DC 2,1A) with BS Plug

Acoustic wall panel 2000 x 1100. Ecilpse

COSY Light. 8W LED. Desk through fix 68cm High with white shade

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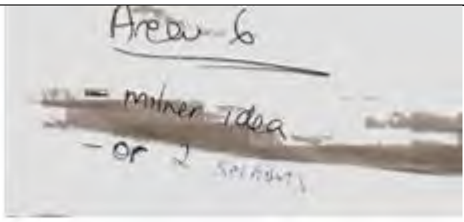
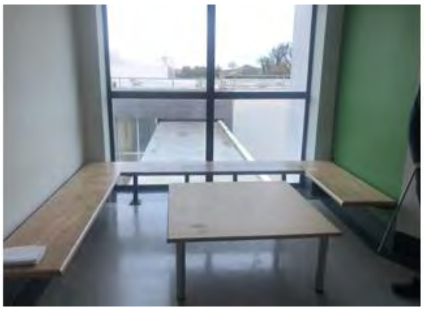
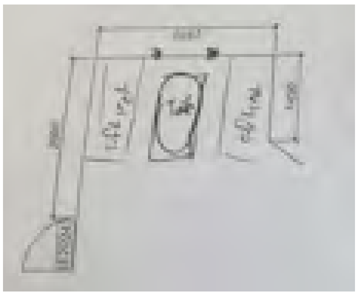
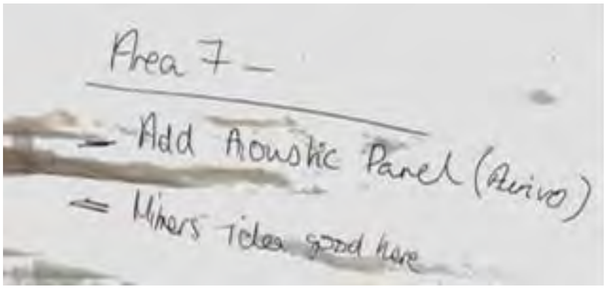
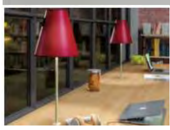
	

Area	Proposed Design
Area 7  **Hackathon Ideas:**  	  **Design Description:** L-Shape sofa comprising 2 seats and 3 cushions, 1 lrge table elements and 1 small table element. SIZE :2925 x 1980 Surround screens. 1310 mm High. 2 rectangular and 1 curved end. Selected fabric Nemo round coffee table 800mm D Charge outlets in tables: 2 USB charger (5V/DC 2,1A) with BS Plug COSY Light. 8W LED. Desk through fix 68cm High with white shade

APPENDIX 3: SEATING AREA NVIVO CODE BOOK

Nodes

Name	Files	References
Current Preferred Seating Area (RQ5)	1	45
Canteen and Surroundings(Theme)	1	13
Canteen	1	10
Canteen - no other option	1	2
Outside Canteen	1	1
Engineering (Theme)	1	6
Engineering 2nd Floor	1	5
New Pod in Engineering	1	1
More Private Areas and Secluded Seating(Theme)	1	17
Computer Labs	1	1
Free Lecture Room	1	2
Library	1	4
Office	1	1
Outside Library	1	7
Reception	1	2
Social Areas (Theme)	1	9
B-Block	1	2
Couch	1	1
D Block	1	5
Student Union	1	1
Don't user (RQ2)	1	34

Name	Files	References
Aesthetic (Theme)	1	11
Uncomfortable	1	7
UnInviting	1	4
Functional (Theme)	1	10
Bad Light	1	6
Cold	1	2
No Charging	1	1
Unsuitable Tables	1	1
Have no need for it (Theme)	1	6
Don't need	1	6
Location (Theme)	1	7
Limited Food Access	1	2
Out of the way	1	2
Too Busy	1	3
Liked Seating (RQ3)	1	67
Aesthetic (Theme)	1	8
Bright	1	4
Calm	1	1
Colourful	1	2
Feels Nice	1	1
Functional Reasons(Theme)	1	16
Access to Lectures	1	1
Access to Studio Classes	1	1
Central	1	1

Name	Files	References
Coffee Nearby	1	1
Food is nearby	1	1
Functional Tables	1	1
Meeting People is Easy	1	2
No other options	1	2
Only Option	1	1
Only sit at Meals	1	1
Space for Laptop Use	1	1
Table	1	1
Table for Laptop	1	2
Heat, power and light(Theme)	1	8
Full of Light	1	1
Good lighting	1	3
Light	1	1
Warm	1	1
Well Lit	1	2
Seating Area Types(Theme)	1	34
Blocked Sound	1	1
Chat and Work	1	1
Comfortable	1	6
Mixed Needs	1	1
No Distractions	1	2
no other people	1	1
Partitions for Privacy	1	1

Name	Files	References
Plenty of seating	1	2
Privacy	1	3
Quiet	1	3
Reduces Anxiety	1	1
Relaxing	1	2
Seat Comfy	1	2
Secluded	1	1
Seperate Seating	1	1
Social Aspect	1	2
Socialable	1	1
Spacious	1	3
Unlike the E-Block	1	1
Recommended Changes Overall	1	106
Aesthetic Changes	1	7
Add Plants	1	1
Colour and Attractiveness	1	6
Add Colour	1	1
Attractive and Inspiring	1	1
Brighter Colours	1	1
Improve Colours	1	2
Some Colour	1	1
Food and Drink Supports(Theme)	1	2
Coffee Facilities	1	1

Name	Files	References
Water Taps	1	1
Heat,Power and Light	1	31
Add Lighting	1	16
Improve Light	1	12
Improve Lighting	1	2
Lighting after 5pm	1	1
Add or Improve Heat	1	4
Improve Heat	1	2
Improve Heat (2)	1	2
Charging and Power Additions	1	11
Charge Points	1	7
Charging	1	1
Monitors for Group work	1	1
Phone Charging	1	1
Sockets_Charge Points	1	1
Seating Changes	1	66
Adding Tables or Table Additions	1	11
Add tables for Books and Laptops	1	1
Elevate Tables	1	1
Higher Tables	1	1

Name	Files	References
Improved Table height for WheelChair	1	1
More Tables	1	1
Seating with Tables	1	1
Support Laptop	1	1
Usable Tables	1	4
Private Seating and Noise Reduction	1	18
Division between traffic	1	1
Individual Seating	1	2
Make Less Busy	1	1
Privacy	1	4
Private Pods	1	2
Reduce Noise	1	4
Seating for private conversations	1	1
Secluded Seats	1	1
Semi Enclosed Seating	1	1
Study Areas	1	1
Seating for Mixing and Collaboration	1	11
Collaborative Seating	1	3

Name	Files	References
Improve for meeting others	1	2
Mixed Seating Types (Social and Private)	1	1
More Seats	1	1
Open plan Seating	1	1
Replicate Business Area	1	2
Seating for Meeting	1	1
Seating Material_Comfort Changes	1	26
Avoid Goldfish Booths	1	1
Improve Seating Material	1	1
More Comfort	1	11
Seats for Comfort	1	9
Seats with Back Support	1	2
Soft Seating	1	2

Amplifying new voices and making space for alternative knowledge systems in engineering curricula – the example of Ubuntu

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ABSTRACT

Engineering projects are ubiquitous; from developing COVID-19 vaccines to building new cities and developing climate change solutions. An inclusive approach to teaching engineers how to master the complexities of engineering project management is vital to the deliverability of sustainability and net zero initiatives (Hockings 2010). Yet, our engineering curricula remain deeply rooted in Western epistemology (Winter *et al.* 2022, Mbembe 2015). Arguably, this is an opportune time to consider decolonising our curricula.
At a fundamental level, 'decolonising the curriculum' means introducing previously ignored voices, images, authors, theories and arguments into our teaching (Rogers

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et al. 2022). This is a challenge in the subject of engineering project management, where we have a rigid body of knowledge that forms the backbone of our curricula. In this paper, we argue that we must not lose the richness of theory, models and processes taught in our engineering curricula. However, we do need to search out or build knowledge of how projects in the Global South or among indigenous peoples may be managed differently and listen to and amplify voices from those cultures and communities. Ubuntu is one such alternative knowledge system, which we propose as an example of how we can amplify new voices within our engineering curricula and begin the work of decolonising our discipline (Metz 2007, Naude 2019). Our paper is based on a critical review of extant literature. We challenge readers with an evidenced call to action to embed the Ubuntu values and its benefits for students into engineering education.

1 INTRODUCTION

Traditional approaches to teaching engineering in Higher Education are based on students achieving mastery of fundamental scientific, mathematical and behavioural concepts and then using this knowledge and experience to engage in engineering design and build projects (Lucas *et al.* 2014, Ramadi *et al.* 2015). Changing employment patterns and rapid advances in technology have led to increasing demands from employers for engineering graduates who are not only technically proficient but also ethically and environmentally literate, adept at project management, self-starting and confident (Zea *et al.* 2014). Many engineering graduates will work on engineering projects, initially in technical roles, but later becoming project managers, building infrastructure, developing new products and delivering climate change solutions. As a consequence, engineering project management has now become an important spine of engineering education and is taught internationally, typically in accordance with the requirements of the engineering and project management professional bodies/institutions.

The context for our paper is that of a large civic modern University in the United Kingdom, with a diverse student body and a strong record of widening participation (for example, 51% of incoming students are first-in-family to attend HE and a third come from the most deprived postcode areas in the UK). However, the UK data shows a persistent 9% Awarding Gap[2] between white students and students from a minority ethnic background (Advance HE 2022). In our own Department of Engineering the Awarding Gap has narrowed over the last 5 years but remains stubbornly high at 11.4%. As engineering educators, we need to address this issue to ensure that the education we are providing does not wittingly or unwittingly disadvantage one group of students over another. The same applies to students arriving with vocational qualifications, disabled students, students who are care-leavers, and other under-represented groups.

An inclusive approach to teaching engineers how to master the complexities of engineering project management is also important to the deliverability of sustainability and net zero initiatives (Hockings 2010). Yet, our engineering project management curricula remain deeply rooted in Western epistemology (Winter *et al.*

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[2] The Awarding Gap is commonly defined as the difference in the percentage of White vs Minority Ethnic students graduating with a 1st or 2(i) degree in any particular academic year.

2022, Mbembe 2015). In this paper we argue that there are ethical and moral imperatives to decolonise our engineering curricula and introduce alternative knowledge systems into our teaching. We begin by defining what we mean by decolonising curricula, why it is important and what its benefits are. We then use the teaching of engineering project management as an example of a subject area that is lacking in alternative knowledge systems. We propose Ubuntu as an alternative knowledge system that we can introduce into our engineering project management curricula as an example of how we can amplify new voices within engineering curricula and begin the work of decolonising our discipline (Metz 2007, Naude 2019).

2 DECONSTRUCTING DECOLONISING: WHAT DOES IT MEAN, WHY IS IT IMPORTANT AND WHAT ARE THE BENEFITS?

At its core, decolonising the curriculum means recognizing and addressing the historic legacy of largely European colonialism resulting in biases and imbalances in the education system. This needs a re-examination of curricula to ensure that they include diverse perspectives, knowledge and approaches to learning from different cultures and backgrounds, and that it incorporates overlooked or marginalized voices, perspectives, experiences and alternative knowledge systems. There is a burgeoning interest in addressing the vestiges of colonial legacy in UK Higher Education Institutions (HEIs) across all disciplines including engineering education. This is consistent with the call for social justice and the need to critique the content and delivery of post-colonial education (Arday *et al.* 2020). Effective decolonisation should create a more inclusive and equitable education system that reflects the diversity of society and prepares students as global citizens.

Winter *et al.* (2022:1), argue that decolonising is "*a socio-political movement which challenges Eurocentrism and post-colonial notions of power*". In this sense decolonising is concerned with highlighting and challenging the ways in which colonialism has impacted on our society, and within it the production of knowledge, our educational structures, curricula and pedagogies. Although education may be perceived as one of the benefits of colonialism, this often came at a cost, including the replacement of indigenous knowledge and education systems by western knowledge. This legacy continues today and is reflected in the 'whiteness' of our curricula in the west. In this respect, we contend that decolonisation of curricula is not only ethical (Rogers *et al.* 2022), but by ensuring that other marginalised voices are represented, it is also a precursor to social justice. Whereas an inclusive curriculum acknowledges the diversity of learners, the barriers different learners face and attempts to remove the barriers, a decolonised curriculum goes beyond this, requiring a "*critical analysis of how colonial forms of knowledge, pedagogical strategies and research methodologies… have shaped what we know... recognise and... reward*" (Arshad 2020:1). Decolonising is not about deleting knowledge, rather it is a re-examination and rebalancing of our curricula by amplifying and integrating a wider range of perspectives in what we teach, how we teach, and the wider learning environment in which we teach (Liyanage 2020).

There are other practical, educational benefits to decolonising the curriculum. Firstly, STEM disciplines have traditionally been dominated by Western-centric knowledge systems. Incorporating a wider range of perspectives into curricula means being more learner-centred and more attuned and reflective of the diversity of our student body. Secondly, by embedding alternative knowledge systems, STEM disciplines become more relevant to local communities and more responsive to their needs. Thirdly, decolonising can contribute to addressing systemic inequalities such as the racialised awarding gaps that exist in Higher Education. The reasons for award gaps are highly complex and systemic (Advance HE 2022). Reflecting this, the range of measures implemented by HEIs to close award gaps across the sector is wide-ranging and includes reviewing the provision of academic and personal support and skills development, creating the conditions to develop learner communities that enhance sense of belonging, and the offer of extra-curricular opportunities that enhance employability. There is scant hard evidence that decolonising curricula leads directly to the closing of award gaps. There is also a lack of clear evidence for successful measures that consistently close award gaps – and this is not surprising given the complex societal, educational, and circumstantial factors that contribute to, and perpetuate award gaps. However, the student voice on decolonising echoes many of the same measures that are being implemented to close award gaps (Nicholson 2022). In short, there is very strong evidence that measures adopted to close award gaps and to decolonise curricula have enormous overlap and are mutually beneficial as curricula become more relevant, inspiring and engaging and promoting the participation of hitherto underrepresented groups.

In decolonising our own discipline of engineering education and in the specific case of engineering project management, it will be important not to lose the richness of theory and models that we have already in the discipline. After all, engineering project management is a practical discipline and our graduates will go on to be employed by organisations who will expect them to be competent experts in the project management Bodies of Knowledge (APM 2019, PMI 2021). However, we do need to make our models and theories more context-specific, to ground them in a wider historical context than the hitherto dominant post-WW2 US defence industry and to challenge the linear view of how engineering projects are initiated, developed and delivered. We could make more use of examples from projects all around the globe. We also need to search out alternative knowledge systems from projects in the Global South or from among indigenous peoples, and discover how projects may be managed differently and amplify voices from these communities.

Prior work on decolonising engineering curricula is limited. Fomunyam (2017) argues that decolonising engineering curricula is a means of improving access to engineering, and Mkansi *et al.* (2018) and Winberg and Winberg (2017) discuss approaches to decolonise our curricula, using, for example, a social justice framework. Interestingly, South African Universities provide the context for each of these studies. We cannot find any studies that focus on what decolonising might entail in engineering project management. This gap in the literature echoes Mbembe (2015) who concludes that decolonising has two sides: "…*a critique of the dominant Western models of knowledge and the development of alternative models. This is where a lot remains to be done.*" (Mbembe 2015:18).

Our paper contributes to this imperative to develop alternative models by introducing Ubuntu as an example of one such alternative knowledge system that could be introduced into engineering project management curricula. The Ubuntu philosophy has been applied in other disciplines such as business ethics (Naude 2017) and food security (Ndhlovu 2023), but we are not aware of any application to the discipline of engineering project management.

3 UBUNTU AS AN EXAMPLE OF AN ALTERNATIVE KNOWLEDGE SYSTEM

3.1 Western Management Philosophy

Before considering Ubuntu, we provide a brief overview of Western management Philosophy (WMP) which prevails as the dominant approach in the west. WMP is rooted in positivism and emphasises capitalist concepts such as profit-making through individualisation, strong hierarchies within the workplace, and private property. Market competition is key, along with exploitation of the price system to maximise profit. There is also optimisation of the value of a project 'owner' and 'leader' (Marnewick *et al.* 2018). In the context of engineering project management one of the tenets of this philosophy is that managers are defined as the only developed actors able to lead a project (Fougére and Moulettes 2009). This sharp distinction derives from the dichotomy that exists in the colonial narrative, a well-established binary position that often represents the 'norm'. Where this binary approach exists, the voices of some stakeholders may be excluded.

As we have already argued, it is not enough to critique the western models without offering viable alternative knowledge systems. In this case, we are proposing Ubuntu as one of the non-western voices that could be amplified within engineering project management curriculum. Whereas WMP privileges certain individuals, Ubuntu draws attention to the value and contribution of *all* stakeholders. At this end of the spectrum, non-western management philosophies such as 'Ubuntu' may provide a potentially more inclusive approach to engineering project management.

3.2 So what is Ubuntu?

Ubuntu is an African humanist philosophy which proclaims cooperation and solidarity among interdependent actors. Ubuntu focuses on respect, solidarity, humanness, empathy, sharing of different opinions, knowledge and skills. The Ubuntu philosophy defines people through their relationships with others, in particular, having mutually beneficial relations (Sartorius *et al.* 2011, Amon and Tripathi 2013, Ruggunan 2016, Sarpong *et al.* 2016, Ochara 2017). Amon and Tripathi (2013) apply the concepts of 'Ubuntu' and 'ujamaa', which can be translated as 'familyhood' to project management, and by extension, to engineering project management. The principle behind Ubuntu is that throughout a project life cycle, *all* stakeholders collaborate, they respect each other's diverse perspectives, traditions, and culture. Rwelamila *et al.* (1999) consider that harmony and symbiosis among stakeholders represent the two key principles behind Ubuntu. In particular, the concept of harmony is used "*as a metaphor that describes the significance of group solidarity on survival issues*" (Rwelamila *et al.* 1999:336).

It is against this backdrop that we invite a reimagining of project management through Ubuntu to create a project environment that is more respectful of participant and stakeholder diversity. In this environment, project participants and all stakeholders ought to see themselves represented more clearly, and there ought to be a more cooperative approach in which all contributions of expertise, opinion and effort are appreciated on an equal basis. There are benefits to this approach. Sarpong *et al.* (2016) suggest that the integration of Ubuntu encourages operational autonomy by valuing every stakeholder's input. This in turn, can nurture imagination and creativity, potentialities, and alternatives, enabling 'foresightful' actions in dynamic contexts. These benefits can be realised in engineering project management.

3.3 Embedding Ubuntu into engineering project management curricula

There are two main schools of thought on the decolonisation of engineering project management curricula using Ubuntu. The first holds that for project management to be decolonised it has to be entirely re-invented (Nkomo 2011, Ruggunan 2016, Marnewick *et al.* 2018). For instance, Marnewick *et al.* (2018:12) posit that "*how the object of study itself is constituted, what tools are used to study it and what concepts are used to frame it should be redefined by focusing on the Ubuntu principles*". The second school of thought rejects the notion of total exclusion of WMP from engineering project management. This view suggests instead, that Ubuntu principles and values be applied within existing project management approaches, thereby bringing adding value Goldman (2016). Arguably, it is impossible to exclude WMP completely, given that it has defined engineering project management as a discipline. We argue that it is not possible to completely undo what the discipline has been before, but that it should be feasible to integrate a new philosophy within our curricula. The profession can be encouraged to develop and embed multiple voices, including different concepts, perspectives and knowledge systems (Frenkel and Shenhav 2006, Hodgson and Cicmil 2008, Ochara 2017). These multiple voices need to be included in textbooks as well as discussed in interactions among different academics and between lecturers and students in classrooms (Marnewick *et al.* 2018).

3.4 Examples of Ubuntu values in curricula

We consider some selected case studies providing useful insights into how this important task can be achieved using Ubuntu principles and values:

1. *Re-evaluating the origins of engineering project management:* The extant literature emphasises the urgency of revaluating the origins of engineering project management (Frenkel and Shenhav 2006, Goldman 2016, Ruggunan 2016, Tennent 2021). In this regard, Ruef and Harness (2009) suggest that project management could be dated back to the 'pre-modern' agrarian age, rather than focusing only on the modern concept of project management that coincided with the onset of the industrial revolution. Ruef and Harness (2009) and Marnewick et al. (2018) suggest that the ancient pyramids represent a form of engineering project management and should be included in engineering curricula. Similarly, "early signs of managerial identity' could be traced back to slave plantations in southern USA (Frenkel and Shenhav 2006:856). As a result, engineering project management should not be studied through the positivist lens only, but rather it should be considered as a social science that depends on subjectivity and multiple perspectives and traditions (Ruggunan 2016).

2. *Strategic foresight:* Sarpong *et al.* (2016:1) focus on the concept of strategic foresight, which refers to "*the ability to identify and (re) configure sources of potentialities and limits into productive outcomes*". In their view, strategic foresight principles are derived from WMP which purports that this ability is not a distributed skill, but rather a capability bound to the manager/leader only, who bases considerations and actions on fixed theories. It is our assertion that by applying the

Ubuntu philosophies such as co-operation, collaboration and mutual respect to our teaching of strategic foresight, students might be encouraged to express their own ideas more freely in engineering project management processes. This would furnish the project with new, hitherto under-used or overlooked inputs and the opportunity to participate in project implementation would distribute responsibility and in turn, enhance project outcomes.

3. Conflict management: Amon and Tripathi (2013) share an analysis of non-governmental organisations' projects in Tanzania, focusing on how to prevent conflicts within the workplace that could undermine a project's realisation. When working in a different environment, project managers should consider the different traditions, culture and views of the employees working on the project. In this case, Amon and Tripathi (2013) suggest training opportunities for all stakeholders, enabling them to understand the project, its purposes, and problems encountered. This then opens up new channels for potential solutions. In this case study, the importance of considering the relevance of the project for the community is underlined. Amon and Tripathi (2013) propose the application of Ubuntu values to avoid and/or manage conflicts among stakeholders (Sayers, 2023). Sartorius *et al.* (2011) provide relevant insights and evidence of improved workplace relationships following the implementation of Ubuntu principles and values. In particular, they provide an example of how Ubuntu philosophy was used by a multinational company to support the handling of workers' dissatisfaction towards company policies. Solutions focused on improving relationships among stakeholders, paying attention to employees' personal lives, and including them in communications and discussions about the project purpose.

4. Measures of success: Bayiley and Teklu (2016) studied the positive effects of Ubuntu principles and values in measuring the success of international development projects. Through a survey, they discovered that international development projects were starting to move away from traditional project success measures, instead, preferring to use intellectual capital as the principal measure of a project's success. Hence, they acknowledge the importance of each stakeholder working and cooperating for project success. On the other hand, Sebolao (2015) provide an example of where minimal involvement of indigenous knowledge in a project constituted a limitation on project development. In this case, even though an *Indigenous Knowledge Systems* policy demands the participation of indigenous communities in project management, the policy is not addressed fully by many organisations (Sebolao 2015). Nevertheless, Sebolao (2015) argues that by integrating indigenous communities and their knowledge and opinion, issues and delays due to unfamiliarity with the environment can often be prevented or addressed more quickly.

4 DISCUSSION: IMPLICATIONS FOR THEORY AND PRACTICE

In this paper, we have argued that there is an ethical and moral imperative to decolonise our engineering curricula and make space for alternative knowledge systems. We began by defining decolonisation, and explaining its importance and benefits. We have articulated the importance of decolonising engineering education to (1) put right the historical and persistent inequalities of the colonial era (Winter *et al.* 2022), and (2) make engineering education more inclusive to better engage and reflect our diverse student populations. We then used engineering project

management as an example of a discipline with very Eurocentric roots, whose extant models and processes would benefit from a wider historical grounding and greater diversity of user cases and contexts. Alternative knowledge systems are another means of bringing new and diverse perspectives into a subject discipline.
Our contribution to theory has been to propose Ubuntu as an appropriate alternative knowledge system that can be introduced into engineering project management curricula to amplify new voices and begin the work of decolonising our discipline. Our contribution to practice has been to provide a call to action to engineering educators to enhance engineering project management curricula through the incorporation of Ubuntu as an alternative knowledge system. We have provided four examples of how Ubuntu might be taught alongside existing bodies approaches to engineering project management education. Viewing engineering projects through the lens of Ubuntu enables us to challenge hitherto western-centric dominant perspectives on the role of stakeholders in engineering projects and the knowledge and power dynamics that exist between project manager and project team. As educators, opening up space for alternative knowledge systems within engineering project management teaching helps us optimise knowledge production and provide a more empowering context for our diverse learners.

Given the hitherto paucity of empirical and theoretical studies on decolonising engineering project management, we identify 3 important areas for future work:

1. Testing our call to action, by incorporating Ubuntu in practical ways into engineering project management curriculum content and delivery and evaluating the impact of this on staff and students. We can then build these examples of alternative knowledge systems into all our engineering curricula, whilst ensuring the curriculum remains aligned with the requirements of engineering professional bodies, and at the same time, becoming more accessible and inspirational for a diverse student body.
2. Developing resources and case studies of engineering project management curriculum content and delivery that incorporates previously ignored voices, images, authors, theories, arguments and learning and assessment activities. and making them available for re-use across the HE sector (e.g. in an online repository). Similar UK-based online repositories of resources on how to decolonise various disciplines (UKHEAwardGap 2022, Nicholson 2022) provide a potential model for implementation.
3. Expanding the discussion and application of Ubuntu beyond engineering project management and into every aspect of engineering education. For example, the principles of Ubuntu could help address Zea's (2014) call for engineers who are ethically and environmentally literate, and able to operate in a diverse and inclusive working environment.

   Engineering projects are and will remain ubiquitous; a key vehicle for achieving net zero, developing sustainable infrastructure and enabling equitable life opportunities for the planet's eight billion inhabitants. Projects are getting bigger and more complex and yet must be delivered more quickly. Embracing modularity and digital technology are two means of mitigating these challenges. But the greatest win for engineering projects will be to harness a plurality of thinking, within cross disciplinary, global, diverse project teams - a vision that is achievable *if* we educate our future engineers in new and inclusive ways.

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Comparing Engineering Students Perceptions of Online and Traditional Face-to-Face Environments During a Problem and Project Based Learning (PBL) Module

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ABSTRACT

Research examining the future of engineering education has highlighted forthcoming challenges for engineering institutions, such as increasing cohort sizes, limited budgets and a demand for the delivery of flexible, diverse and student-centred curricula. To this end, scholars have suggested the use of problem and project based learning (PBL) methodologies that can be implemented within hybrid learning environments. This paper examines and compares students' perceptions of a PBL module that was delivered by means of online and traditional face-to-face environments. The goal of this paper is to highlight the students' voice over other stakeholders to provide valuable insights into their preferences of current pedagogical practices. This in turn can provide information to improve teaching and learning in hybrid learning environments. This study was carried out with two student cohorts of first year engineering students. One of the cohorts completed the module in 2021 (N=94) in an online environment and the second in 2022 (N=89) in a traditional face-to-face environment. This paper focus on analysing the 2022 cohort and comparing the results against the findings presented at SEFI 2022 in Barcelona for the 2021 cohort. The findings revealed areas of significance for educators conducting PBL within online and hybrid environments. This includes the role of communication, module planning, dealing with conflict, and flexibility in learning.

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1 INTRODUCTION

1.1 Background

As engineering education begins to move to more flexible learning environments, such as online and blended, using student centered active learning strategies, such as problem and project based learning (Graham 2018; Hadgraft and Kolmos 2020), educators are expected to implement evidence informed pedagogies. However, in recent years the COVID-19 pandemic has highlighted many deficiencies in our current approaches to PBL in online and blended environments (Khandakar et al. 2022; Supernak, Ramirez, and Supernak 2021; Beneroso and Robinson 2022). Additionally, development of effective pedagogical strategies are also stifled due to a known publication bias in reporting positive findings over negative in PBL research (Kolmos and de Graaff 2014). If we are to develop effective pedagogical strategies for PBL within online and blended environments, we must report on and review research that outlines both the success and the failures of current engineering programs.

1.2 Context of the study

In this paper we uncover factors that affect student perceptions of PBL in the traditional face to face environment. This is done with the objective of comparing these factors against the ones presented in an earlier study (O'Connor et al. 2022), completed within the same module, in an online environment. By developing a clearer understanding of the factors that affect student perceptions of PBL in both the traditional face to face environment and online environment, we can proactively develop effective pedagogy strategies for hybrid environments.

1.3 Research Questions

This research paper aims to identify how engineering students perceive PBL in the traditional face to face environment, while also comparing the findings against the online environment. To accomplish this goal the following research questions will be addressed:

a) What factors enhance and/or inhibit the success of PBL in traditional face to face environments as perceived by students?
b) How do the factors compare against the one presented within the online environment?

2 TERMONOLOGY AND DEFINITIONS

2.1 Problem and Project based learning (PBL)

Both problem based learning and project based learning are considered two similar, but separate, teaching and learning strategies commonly used within engineering education. These two teaching and learning strategies are often used interchangeably; however, they are two distinct strategies that have unique features. However, in this paper will be using the hybrid approach know as problem and project based learning or the abbreviation PBL (Kolmos 2017; Edström and Kolmos 2014; Chen, Kolmos, and Du 2020). Problem and project based learning can be defined as *"a very comprehensive system of organizing the content in new ways and students' collaborative learning, enabling them to achieve diverse sets of knowledge, skills, and competencies"* (Kolmos and de Graaff 2014, 147).

2.2 Online learning

Online learning can be defined as *"education being delivered in an online environment through the use of the internet for teaching and learning. This includes online learning on the part of the students that is not dependent on their physical or virtual co-location. The teaching content is delivered online and the instructors develop teaching modules that enhance learning and* *interactivity in the synchronous or asynchronous environment"* (Singh and Thurman 2019, 302).

2.3 Blended learning

Blended learning can be defined as *"defined as a combination of digital and face-to-face content delivery method"* (Bouilheres et al. 2020, 3050). Blended learning is often also referred to as hybrid learning.

3 METHODOLOGY

3.1 Approach

This study was carried out over an academic semester in a first-year engineering module. The data was gathered in two consecutive phases. The data was gathered with the use of open-ended questions (Phase 1) and a semi-structured interview (Phase 2). The capstone project within the module was a Conceive, Design, Implement and Operate (CDIO) project, which was informed by combining both PBL and CDIO pedagogies (Edström and Kolmos 2014). During this project students designed and manufactured a miniature battery-powered vehicle to fulfil a given design brief.

3.2 Participants

The module had 173 students enrolled. Students' ages vary; however, the majority of students are aged between 17 and 19 years. The questionnaire had a participation rate of 51% (N =89), 23 female (26%) and 66 male (74%).

3.3 Module structure

The teaching team for Introduction to Design for Manufacture is made up of two joint module leaders with the support of additional teaching assistants (TA) and laboratory technicians. The module goal is to develop knowledge around basic manufacturing processes and fundamental design skills. The lectures were delivered by the co-leading lecturers, while the laboratories were delivered by TA's. The technicians provided technical support through recorded videos, which was required during the manufacturing phase of the project. The project was designed, built and tested by students in teams over a twelve-week semester. The project was broken down into three challenges. Week 1- 4 was an individual challenge where students developed individual design ideas. Weeks 6, 7 & 8 saw a teamwork challenge introduced, where students were paired into teams of 5 based on their results from the individual challenge and their preferred role on the team. Team leaders were also appointed based on results from the individual challenge. On completion of the teamwork challenge, teams submitted a design portfolio. Week 9-11 was a manufacturing challenge where teams used their design portfolio to develop a physical artifact. Week 12 was vehicle time trials, where all completed projects were tested and timed.

3.4 Instruments

Open-ended questions (Phase 1): The first three open-ended questions were developed by Ku, Tseng, and Akarasriworn (2013) with the remaining question being developed by the first author of the paper.

Semi-structured interviews (Phase 2): The semi-structured interviews were designed using the results of the student attitude survey, teamwork satisfaction survey and open-ended questions. Points of interest from the preliminary analysis of the surveys and open-ended questions were developed into semi-structured interview questions to further probe the participants' answers.

3.5 Data Collection

Participant responses were collated into one Microsoft Forms document. The questionnaire and open-ended questions were distributed to students of the module over email and at the end of a weekly lecture after completing the capstone team-based project. Microsoft Forms recorded all the participants' responses.

3.6 Data Analysis

A six-phase Inductive thematic analysis approach was undertaken to investigate both the open-ended questions and semi-structured interview datasets (Braun and Clarke 2022). The main goal of the thematic analysis was to identify what factors affect students' perceptions of team PBL in the online environment. All data from the open-ended questions and semi-structured interviews were uploaded to NVivo, however the process was carried out with a mixture of both physical and digital documents to help identify all relevant codes, themes, and sub-themes.

3.7 Trustworthiness

A number of processes were used to ensure the reliability and validity of the study, including 1) member (Authors) checking of interpretation of the findings, 2) methodical methodology section covering all study procedures, 3) preregistration and 4) open-source dataset available on *Open Science Framework* (OSF). OSF Link: [Insert link here]

3.8 Ethical Considerations

The study explained in detail to participants the aim and objectives of the research. All participants provided consent. Students were clearly informed that participation was voluntary and that they could withdraw from the study at any stage without consequence. All data was collected, organised and stored according to the host university's data handling policy which is GDPR compliant. All student identifiers were removed to protect anonymity. Ethical approval was provided by the host university.

4 RESULTS AND DISSCUSSION

4.1 Overview

A thematic analysis was utilised on the data from three of the four open-ended questions and all the semi-structured interviews, to highlight factors (Themes) that affect students' perceptions of team PBL in the traditional face to face environment. The following four themes and seven sub-themes, shown in **Error! Reference source not found.**, were outlined to affect students' perceptions of team PBL in the traditional face to face environment.

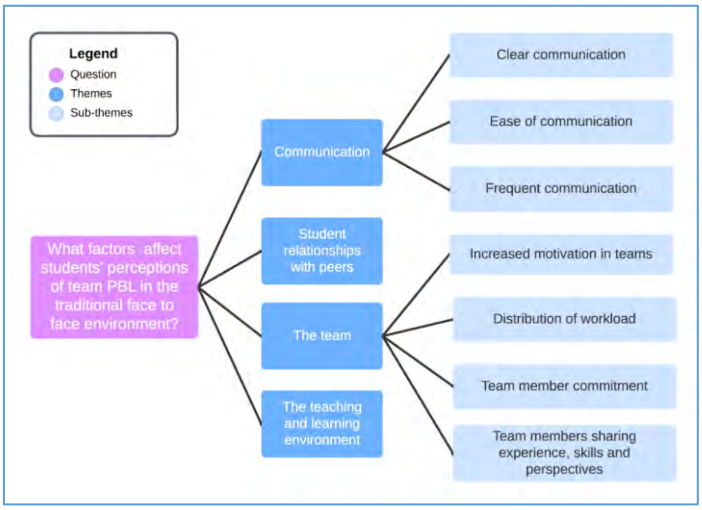

Fig. 1 Thematic Analysis Flow Diagram

4.2 Themes and Sub-Themes

Theme 1 - Communication: In this paper, communication was the second most discussed theme by participants. The theme communication also included three sub-themes A) clear communication, B) ease of communication and C) frequent communication.

Sub-Theme A: Clear communication: Clear and coherent communication was important to participants. A number of participants outlined the need for clear communication among team members: *(P. 39) "I enjoyed working with the group as I felt it really helped with the project. Meeting regularly on campus was very good for our collaboration. It meant we could all explain ourselves clearly and coherently, and no one struggled with connectivity problems or other tech issues. We could do up little sketches and paper models as we designed and show them to each other and collaborate on them in real time".* Many authors have also outlined the necessity for effective oral communication when working in technical disciplines (Darling and Dannels 2003).

Sub-Theme B: Ease of communication: The ease with which peers could communicate was also highlighted by several participants. One participant stated that the ease at which they communicate is vital to their progress within the project: *(P. 63) "i found it easier to analyse and solve any problems that arose when we could speak (…) bouncing ideas off each other until a solution was found, rather than waiting on texts or arranging video calls"*. Similarly, Nordstrom and Korpelainen (2011) outlined, that the ease of communicate between their students directly impacted their learning will engaging in teamwork.

Sub-Theme C: Frequent communication: Participants also stated that team communication needed to occur on a regular basis. One participant outlined how a lack of communication from one team members was damaging to the team's progress: *(P. 14) "I dislike the collaborative work, as my team members rarely communicate and often miss deadlines or meetings without notice".* Other authors, such as Iacob and Faily (2019), also state that participants highlight the positive role regular meetings played in the team's progress.

Theme 2 - Student relationships with peers: Numerous participants noted that they enjoy engaging in PBL within the traditional face to face environment as it provides them with the opportunity to develop new friendships: (P. 20) *"I enjoy working as a group as it is a good opportunity to meet new people and learn from each other"* and (P. 84) *"the ability to meet new people and interact with them on a regular basis was extremely helpful"*. Providing opportunities for undergraduate engineers to socialise with peer and develop interpersonal skills is important because the more developed the social skills the more chances to satisfactorily deal with the demands of different environments and interlocutors (Lopes et al. 2015)

Theme 3 - The team: The participants made reference to a number of factors that affect students' perceptions of PBL in the traditional face to face environment from within the team itself. For this reason, this theme included five sub-themes entitled A) Increased motivation in teams, B) distribution of workload C) team member commitment, and D) team members sharing experience, skills and perspectives.

Sub-Theme A: Increased motivation in teams: A few participants outlined that they experienced increased levels of motivation when working with others: (P. 29) *"I liked working as a group as it increased my motivation and I learnt from others' knowledge"* and (P. 47) *"working as a group helped to motivate each other to reach goals and due dates"*. Although increased levels of motivation is a common finding report by participants engaging in teamwork (Fini et al. 2018; Jun 2010), it's also common to see decreased levels of motivation due to team conflict and or social loafing (Borrego et al. 2013).

Sub-Theme B: Distribution of workload: A commonly shared benefit by participants was the distribution of work among team members: (P. 26) *"We could share the workload".* One student noted that the time constraints on the work meant that completing the project to a high standard wasn't possible if done alone: (P. 30) *"Unless I was given far more time in the manufacturing stage, I would not have been able to complete it alone, and I feel it wouldn't have been as high quality".* PBL strategies aim to simulate real world engineering environments by providing problem that require students to distribute work among team members to meet tight deadlines. This encourages students to develop a variety of team associated soft skills such as communication, reflection, self-regulation and commitment (Palmer and Hall 2011).

Sub-Theme C: Team member commitment: On a number of occasions participants discuss their team in a positive light: (P.76) *"I enjoyed working as a group. Mainly because I was lucky to be placed in a very competent team with a very strong team leader"*. However, some participants also noted having non-committed team members that affect their performance: (P. 58) *"There was also a huge difference in how much each member cared. I cared very much about the project and wanted to make it as good as possible, some just wanted something that moved to get the 6 marks. I found trying to get these people to do just about anything to a decent level very frustrating".* Borrego et al (2013) outlines in a systematic review, that issue such as social loafing and team conflict are often combated by building trust among team members to ensure equal team effort.

Sub-Theme D: Team members sharing experience, skills and perspectives: Not only did participants noted that team members shared information that helped the collective project but also information that develop their own skill: (P. 4) *"my teammates helped me understand more about this project",* (P. 21) *"I learned a lot more by working with teammates as we shared our knowledge on different topics" and* (P. 35) *"I liked with collaboratively in this module as we were able to combine everyone's good ideas and make it into one great idea"***.** Peer learning is one of the many benefits experienced by students during teamwork activities (Volkov and Volkov 2015).

Theme 4 - The teaching and learning environment: As participants were recently impacted by the COVID-19 pandemic restrictions, many students highlighted their appreciation for working within the traditional face to face environment: (P. 27) *"I always enjoy working as a group on campus, it is a lot more interactive and it's also such a nice way to create friendships".* Although many students were pleased to have the opportunity to engage with team members face to face they also outlined issues related to locating group meeting spaces on campus: (P. 19) *"Meeting rooms, I would say. It's a very odd thing, I think, but it's difficult to get a space that is very easy to work in because going to the library, you have to fight for an appointment. And if you don't have an appointment, you go to the working areas which are really, really filled. And that takes too much time to try to organise. Having somewhere that you can just go into with your group to get things done, I think would be really, really helpful with group projects". While this particular issue is related more to the university as a whole, it is still relevant factor that affects students' perceptions within the module.*

4.3 Comparing the Themes Against the Online Environment

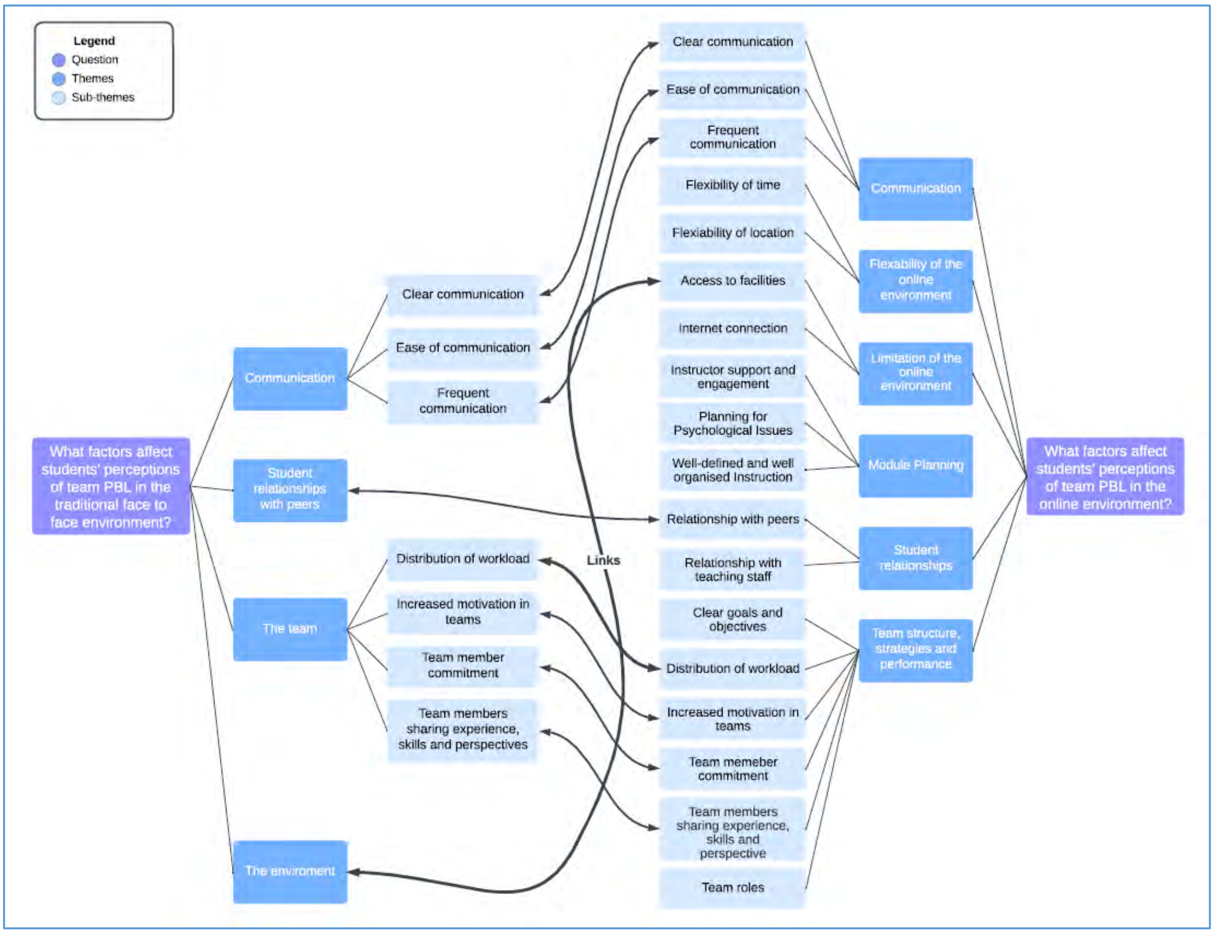

Fig. 2 Thematic Analysis Comparison Flow Diagram

When comparing the factors that affect students' perception of team PBL in the online environment (O'Connor et al. 2022) and traditional face to face environment, as shown in Fig. 3, we can see many commonalities shared between both environments. The strongest commonality shared between both environments fall under the themes entitled communication and the team.

The theme communication and linked sub-themes clear communication, ease of communication and frequent communication, are both clearly highlighted by participants as factors affecting students' perceptions of team PBL in both the online and traditional face to face environments. One of the core learning objectives, for PBL in engineering education, is developing students' transferable skills, such as communication, problem solving, and self-directed learning (Chen, Kolmos, and Du 2020; Edström and Kolmos 2014). Observe participants in both environments highlighting effective communication as a key factor affecting team performance is encouraging. As this provides them with the opportunity to develop and refine a variety of communication skill for working collaboratively. Nevertheless, educators facilitating such interactions between students must be aware of the pitfalls and success experienced by students, so that they in turn, develop effective pedagogical approaches for teaching and learning to assist students developing such skills.

The theme entitled the team and linked sub-themes distribution of workload, increased motivation in teams, team member commitment, and team members sharing experience, skills and perspectives, were also factors shared between participants in both the online and traditional face to face environments. In a similar way to communication, developing teamwork skills is also a key learning objective, for PBL in engineering education. In fact, PBL by design is a team-orientated active and student-centred learning strategy (Kolmos and de Graaff 2014). For this reason, it's clear to see why factors relating to the team play such an important role in each environment.

However, it's worth noting that several factors become less or, in some cases, non-significant to the participants depending on the environment in which they are engaging in. From participant responses, shown in Fig. 3, the range of factors affecting students' perceptions of team PBL in the online environment is greater than within the traditional face to face environment. Although some references were made to these additional factors, such as module planning and flexibility of the environment, the number of occasions didn't warrant the inclusion of an additional theme or sub-theme. Interestingly, one of these missing factors was overwhelmingly positive when identified in the online environment. This factor related to the increased levels of flexibility in time and location experienced by students in the online environment. Students, in general, perceive, that online learning allows for more effective use of time than traditional on campus courses (Bir and Ahn 2017; Young Roby and Hampikian 2002).

4.4 Significance of the findings:

The findings present in this study identifies how engineering students perceive PBL in the traditional face to face environment, while also comparing the findings against the online environment (O'Connor et al. 2022). As we move further towards engineering education that provides more flexible learning environments, such as blended, using student centered active learning strategies, such as problem and project based learning (Graham 2018; Hadgraft and Kolmos 2020), we can use such findings to inform teaching and learning. The findings can provide engineering educators with the foresight to pre-emptively implement strategies to solve issues before they occur. While also selectively choosing and combining elements that work better in either traditional face to face learning and online learning to create an ideal teaching and learning experience (Alkhatib 2018)

5 CONCLUSION

In summary, several factors enhance and or inhibit the success of PBL for participants in the traditional face to face environment. Each of these factors are also outlined and discussed by a number of academics in the engineering education literature base for PBL. This only solidifies the significance of each factor when planning for PBL.

Additionally, when comparing the factors identified in the online and traditional face to face environment, we can see that a number of factors are shared between both. However, there is a number of factors that are unique to the online environment. All of these factors, unique or shared, require careful consideration by engineering educators when planning and executing PBL. The findings clearly outline differences between the environments from participant responses and thus they should require individual tailored pedagogical approach to teaching and learning depending on the chosen environment, as one size won't fit all.

In the case of a blended environment these factors can also be used to inform engineering educator on elements better suited to either online or face-to-face teaching and learning. This will help engineering educators combine the most effective elements of each environment to create an ideal teaching and learning experience.

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Teamwork Satisfaction and Student Attitudes Towards Online Learning During an Engineering Problem and Project Based Learning (PBL) Module

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ABSTRACT

Research has shown that students that report high levels of learner satisfaction and positive attitudes are more likely to succeed within the online environment. This is reflected in the considerable body of research that focuses on these factors across a range of academic disciplines. By assessing students' attitudes and satisfaction, educators gain a valuable affective perspective that allows for a more complete examination of strategy effectiveness. This paper examines teamwork satisfaction and student attitude towards online learning, while also highlighting elements of successful online collaboration as identified by students using the instruments developed by Hasler-Waters & Napier, Ku et al, *and* Tseng et al. This case study was carried out over a seven-week period with first-year engineering students (N=94), in a module entitled *Design for Manufacture*, during the COVID-19 pandemic. The findings revealed high levels of student satisfaction and attitudes towards working in teams in the online environment while participating in problem and project-based learning (PBL). Additionally, the findings outline multiple factors that affect the success of online collaboration. The relevance of these findings is then discussed in the context of an increasing move towards blended and online engineering education provision.

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1 INTRODUCTION

1.1 Background

Engineering education is experiencing a global shift in how students and educators interact during the teaching and learning process (Graham 2018; Hadgraft and Kolmos 2020). As technology advances and the needs of key stakeholders evolve, new challenges emerge for engineering education. These challenges, in turn, can lead to the development and implementation of new and renewed approaches to teaching and learning, that are responsive to the stakeholders' needs and support quality teaching and learning in engineering classrooms.

In recent years, discussions around the future of engineering education have highlighted many challenges facing engineering education institutions (Hadgraft and Kolmos 2020; Graham 2018). One of these challenges includes the delivery of student-centred active learning to large student cohorts with limited institutional budgets (Graham 2018; Hadgraft and Kolmos 2020). To address this challenge, engineering education institutions are increasingly using student-centred active learning approaches, such as problem and project-based learning (PBL), in online and blended learning environments.

However, in recent times the COVID-19 pandemic has highlighted a deficiency in evidence-based pedagogy for online and blended PBL education (Asgari et al. 2021; Syauqi, Munadi, and Triyono 2020). This deficiency in evidence-based pedagogy has emphasised the need for a new body of research to support the implementation of pedagogical strategies in these adopted digital environments.

1.2 Context of the study

In this paper, we investigate engineering students' teamwork satisfaction, attitudes towards online learning and elements of successful online collaboration, as identified by students during the COVID-19 pandemic. Findings will then be compared to similar research within the field including a previously published qualitative study on the same cohort of engineers published by the authors of this paper (O'Connor et al. 2022).

1.3 Research Questions

This research paper aims to use quantitative data analysis tools to provide an overview of student's perspectives of PBL conducted in an online learning environment. To accomplish this goal the following questions are addressed:

a) What degree of teamwork satisfaction is outlined by students during a PBL task in the online environment?
b) What are students' attitudes toward working collaboratively in an online environment during a PBL task?
c) What elements do engineering students perceive to be embedded in successful online collaboration?

2 LITERATURE REVIEW

2.1 Problem and Project based learning (PBL)

This paper utilises a hybrid active learning approach combining both problem-based learning and project-based learning which is commonly referred to as the abbreviation PBL for short. The popularity of this abbreviation is somewhat misfortunate as it is commonly used for a range of different pedagogical strategies in education such as place based learning, problem based learning and project based learning. Nevertheless, problem and project based learning (PBL) can be defined as *“a very comprehensive system of organizing the content in new ways and students' collaborative learning, enabling them to achieve diverse sets of knowledge, skills, and competencies"* (Kolmos and de Graaff 2014, 147).

2.2 Online learning

Online education can be defined as *“education being delivered in an online environment through the use of the internet for teaching and learning. This includes online learning on the part of the students that is not dependent on their physical or virtual co-location. The teaching content is delivered online, and the instructors develop teaching modules that enhance learning and interactivity in the synchronous or asynchronous environment”* (Singh and Thurman 2019).

2.3 Problem and Project based learning during the COVID-19 pandemic

During the COVID-19 pandemic, many higher-level institutions were forced to move to online and blended learning environments to ensure student learning outcomes were fulfilled (Khandakar et al. 2022). This transition was particularly hard for engineering institutions who were trying to adapt current PBL strategies. PBL by design is a team-orientated active and student-centred learning strategy. The online environment poses some challenges for team-orientated activity when compared to traditional face-to-face environments (Saghafian and O’Neill 2018). These issues include a lack of effective communication among team members (Clark and Gibb 2006), issues with building relationships (Lee et al. 2006) and an increase in social loafing (Olson-Buchanan et al. 2007).

Research conducted during the COVID-19 pandemic on online PBL also highlights many of the same recurring issues. Studies during the COVID-19 pandemic have shown that courses and student outcomes that had to rely on laboratory experiments and teamwork tended to be the ones significantly negatively affected by COVID-19 restrictions (Khandakar et al. 2022; Supernak, Ramirez, and Supernak 2021).

Stakeholders’ attitude towards the use of active learning strategies in distance education is mixed with both positive and negative points (Mielikäinen 2022). However, a commonality shared by a number of academics is the need to further develop pedagogical strategies to support the teaching and learning process online (Asgari et al. 2021; Graham 2018; Syauqi, Munadi, and Triyono 2020). The literature on PBL used within the online environment is still lacking sufficient attention to develop trusted evidence-based practices. This paper adds to the current body of literature by helping to identify areas of attention for engineering practitioners attempting to implement PBL online.

3 METHODOLOGY

3.1 Approach

This study was carried out at an Irish university over an academic semester in a first-year engineering module. The module was conducted using a strictly online format due to the Irish governmental restrictions around COVID-19. All elements of the module were delivered online. The capstone project within the module was a team based Conceive, Design, Implement and Operate (CDIO) project, which PBL based and aligned with a CDIO philosophy (Edström and Kolmos 2014). During this project students designed and manufactured a miniature battery-powered vehicle to fulfil a given brief. Quantitative data was gathered with the use of two combined questionnaires and a single open-ended question.

3.2 Participants

The module had 170 students enrolled, 34 female (20%) and 136 male (80%). Students ages vary; however, the majority of students were aged between 17 and 19 years. The questionnaire had a participation rate of 55% (N = 94), 19 female (20.2%), 74 male (78.7%) and 1 preferred not to say (1.1%).

3.3 Online module structure

The teaching team for *Introduction to Design for Manufacture* is made up of two joint module leaders with the support of additional teaching assistants (TA) and laboratory technicians. The module goal is to develop knowledge around basic manufacturing processes and fundamental design skills. The module was fully completed off campus remotely by students. The lectures were delivered by co-leading lecturers, while the laboratories were delivered by TA's using Microsoft Teams. The technicians provided technical support through recorded videos, which, assembled and tested during the manufacturing phase of the project. The project was designed by students in teams over a twelve-week semester. The project was broken down into three challenges. Week 1-4 was an individual challenge where students developed individual design ideas. Weeks 6, 7 & 8 saw a teamwork challenge introduced, where students were paired into teams of 5 based on their results from the individual challenge and their preferred role on the team. Team leaders were also appointed based on results from the individual challenge. On completion of the teamwork challenge, teams submitted a design portfolio. Week 9-11 was a manufacturing challenge where teams used their design portfolio to develop a physical artifact. Due to the Covid-19 pandemic the teaching team prepared all components and sent them out to a nominated student from each team for final assembly. Week 12 was vehicle time trials, where all completed projects were tested and timed.

3.4 Instruments

The study utilised three instruments:

a) Teamwork student satisfaction scale developed by Tseng et al. (Tseng et al. 2009). The Cronbach's alpha reliability for the scale was reported as 0.95 (Ku et al., 2013).
b) Online collaborative attitude scale developed by Tseng et al. (Tseng et al. 2009) based on Hasler-Waters & Napier (Hasler-Waters and Napier 2002) five collaboration factor model. The Cronbach's alpha reliability for the scale was outlined as 0.95 (Ku, Tseng, and Akarasriworn 2013).
c) The open-ended question was developed by Ku et al. (Ku, Tseng, and Akarasriworn 2013).

Both questionnaires used a five-point Likert scale to measure respondents' agreement with various statements. The scale ranges from 1 (Strongly disagree) to 5 (Strongly agree). All instruments are available on the Open Science Framework (OSF) [https://osf.io/4d2cz/?view_only=bbdf738274c54013a0bfdce7d3042204].

3.5 Data Collection:

Participant responses were collected using the Microsoft Forms platform. The questionnaire and open-ended question were distributed to students of the module over email and at the end of a weekly lecture after completing the capstone team-based project.

3.6 Data Analysis

The questionnaire data was analysed using IBM SPSS Statistics software. The questionnaire results were represented for both male and female participants. The questions were also ranked in order of agreement. The open-ended question was analysed by counting the number of reoccurring elements, as outlined by students, of a successful online collaborative setting.

3.7 Reliability and Validity

Several additional processes were followed to strengthen the reliability and validity of this study including, 1) preregistration on OSF to ensure sufficient transparency, 2) methodical methodology section covering all study procedures, 4) open access anonymized data file and questionnaire provided on OSF to facilitate independent re-analysis, 5) member checking of researcher interpretations of findings and lastly 6) the calculation of the Cronbach's alpha, which is a measure of internal consistency.

3.8 Ethical Considerations

An information sheet was provided to all participants outlining the aim and objectives of the research. Participants provided informed consent before accessing the survey. Students were clearly informed that participation was voluntary and that they could withdraw from the study at any stage without consequence. All data was collected, organised and stored according to the host university's data handling policy which is GDPR compliant. All student identifiers were removed to protect anonymity. Ethical approval was granted by the host university.

4 RESULTS

4.1 Online Collaborative Attitude

In *Table 1*, each of the 20 items were analysed and ranked in order of agreement. The mean, standard deviation and overall mean rank are also shown. The overall mean result of 3.916 shows a high level of student positive agreement with their collaborative learning experiences in the online environment. The Cronbach's alpha reliability for the scale was 0.827. The online collaborative attitude scale included three underlying factors (F1) team dynamics, (F2) team acquaintance and (F3) instructor support. The Cronbach's alpha reliability for each of these factors were 0.850 for F1, 0.452 for F2 and 0.705 for F3.

Table 1: Students Online Collaborative Attitude Scores

Questions no.	Survey items	Male mean	Female mean	OA mean	Male SD	Female SD	OA SD	OA mean rank
20	My team members clearly know their roles during the collaboration.	4.460	4.632	4.5	0.623	0.496	0.600	1
11	Communicating with team members regularly helps me to understand the team project better.	4.351	4.474	4.372	0.607	0.513	0.586	2
10	My team members communicate in a courteous tone.	4.230	4.421	4.277	.653	0.507	0.629	3
4	My team is receiving feedback from each other.	4.230	4.368	4.255	0.562	0.597	0.567	4
16	My team trusts each other and works toward the same goal.	4.270	4.211	4.255	0.556	0.787	0.604	5
12	My team members encourage open communication with each other.	4.108	4.316	4.149	0.632	0.671	0.639	6
15	I trust each team member can complete his/her work on time.	4.135	4.158	4.138	0.709	0.898	0.742	7
18	My team sets clear goals and establishes working norm.	4.108	4.211	4.128	0.674	0.713	0.676	8

9	My team members communicate with each other frequently.	4.068	4.316	4.117	0.800	0.582	0.760	9
8	Getting to know one another in my team allows me to interact with teammates more efficiently.	4.095	4.158	4.106	0.706	0.688	0.695	10
14	My team members reply all responses in a timely manner.	3.932	4.263	4.000	0.689	0.806	0.718	11
19	My team has an efficient way to track the edition of documents.	3.892	4.158	3.936	0.945	0.834	0.925	12
17	My team develops clear collaborative practices to increase team learning efficiency.	3.757	3.895	3.787	0.755	0.809	0.760	13
13	My team members learn how other members wish to be treated and then act accordingly.	3.716	3.947	3.766	0.693	0.780	0.710	14
1	My team is receiving guidance for the group project from the instructor(s).	3.770	3.632	3.734	0.732	0.597	0.706	15
7	My team members share their professional expertise.	3.622	3.895	3.670	0.855	0.875	0.860	16
6	My team members share personal information to know each other better.	3.500	3.474	3.489	0.925	0.905	0.913	17
3	The support from the instructor(s) helps my team to reduce anxiety among team members.	3.487	3.474	3.479	0.763	0.612	0.729	18
5	My team members share cultural information to know each other better.	3.297	3.000	3.234	1.095	1.000	1.072	19
2	The instructor(s) acts as a referee when our members cannot seem to resolve differences.	2.960	2.790	2.926	0.784	0.713	0.765	20
Overall		3.899	3.990	3.916	0.136	0.146	0.128	

Please note: Responses range from 1 (Strongly disagree) to 5 (Strongly agree). OA: Overall, SD: Standard deviation.

4.2 Student Teamwork Satisfaction

On completion of the student teamwork satisfaction scale, each of the 10 items was analysed and ranked in order of agreement. The mean, standard deviation and rank are shown in *Table 2*. The overall mean score of the student teamwork satisfaction scale was 4.011, which shows a high level of student positive agreement with their level of teamwork satisfaction in the online environment. The Cronbach's alpha reliability for the scale was 0.868.

Table 2: Students Teamwork Satisfaction Scores

Questions no.	Survey items	Male Mean	Female Mean	OA Mean	Male SD	Female Mean	OA SD	OA mean rank
4	I have benefited from interacting with my teammates.	4.162	4.632	4.255	0.597	0.496	0.604	1
9	My team members are sharing knowledge during the teamwork processes.	4.149	4.316	4.181	0.612	0.749	0.639	2
5	I have benefited from my teammates' feedback.	4.095	4.368	4.149	0.743	0.761	0.747	3
3	Interacting with the other members can increase my motivation to learn.	4.095	4.316	4.138	0.743	0.749	0.742	4
6	I enjoy the experience of collaborative learning with my teammates.	4.041	4.316	4.096	0.650	0.946	0.719	5
10	I gain online collaboration skills from the teamwork processes.	4.068	4.105	4.076	0.782	0.809	0.779	6
2	I like solving problems with my teammates in group projects.	4.041	4.053	4.043	0.784	0.705	0.761	7
8	Working with my team helps me produce better project quality than working individually.	3.919	4.105	3.957	0.962	0.875	0.938	8
1	I like working in a collaborative group with my teammates.	3.946	3.947	3.947	0.935	0.621	0.872	9
7	Online teamwork promotes creativity.	3.203	3.526	3.266	1.007	1.073	1.018	10
Overall		3.972	4.168	4.011	0.145	0.162	0.128	

Please note. Responses range from 1 (Strongly disagree) to 5 (Strongly agree). OA: Overall, SD: Standard deviation.

4.3 Elements of Successful Online Collaboration

The open-ended question was designed to identify what students viewed as important elements embedded in a successful online collaborative setting. The question was presented to participants as the following: *In your opinion, what elements should be embedded in a successful online collaborative setting?* After completion of data analysis, the authors were able to be identified 12 recurring elements of successful online collaboration from participant comments. Some of the categories used were supported by the elements identified by Ku et al. (Ku, Tseng, and Akarasriworn 2013).

Table 3: Elements of successful online collaboration

No.	Elements embedded in a successful online collaborative setting	Count (Ranked)
1	Frequent communication	26
2	Team commitment	24
3	Clear communication	19
4	Clear objectives and goals	13
5	Synchronous meetings	9
6	Camaraderie	9
7	Use of interactive software	8
8	Instructor support and encouragement	7
9	Timely resources	6
10	Member Rolls	6
11	Well-defined and well-organized instruction	5
12	Opportunities to access and view examples	3

Please note. Count: Frequency of element in participant response*s*.

Each of these elements has share commonalities with the findings presented by the authors in a recent publication, on the same cohort, reporting on factors that affect students' perceptions of problem and project-based learning (PBL) in an Online Learning Environment (O'Connor et al. 2022). Within this publication the authors outlined six themes and eighteen sub-themes affecting students' perceptions of PBL in the online environment. Some of the closest linked themes include:

Theme 1) Communication: The theme communication linking with the element's entitled frequent communication, clear communication, synchronous meetings, and instructor support and encouragement.

Theme 2) Module planning: The theme module planning linking with the elements entitled use of interactive software, instructor support and encouragement, timely resources, well-defined and well-organized instruction, and opportunities to access and view examples.

Theme 3) Team structure, strength, and performance: The theme team structure, strength, and performance linking with the elements

5 DISCUSSION

Overall, the participants showed high levels of teamwork satisfaction while participating in PBL within the online environment. This was a significant finding for the study, as student satisfaction is a widely accepted measure of the quality and effectiveness of teaching and learning (Wu, Tennyson, and Hsia 2010). In addition, student satisfaction has also been closely linked with student motivation, dropout rates and future recommendation to prospective students (Butt and Rehman 2010; Mai 2010; Sneyers and De Witte 2017) The numerous benefits from high levels of student satisfaction are clear within the available literature and as such is seen as an indicator of program quality within engineering (Sneyers and De Witte 2017). This high level of satisfaction was similar to results presented by Ku et al., (Ku, Tseng, and Akarasriworn 2013) and Tseng et al., (Tseng et al. 2009) who both implemented the same teamwork satisfaction questionnaire. Both Ku et al., (Ku, Tseng, and Akarasriworn 2013) and Tseng et al., (Tseng et al. 2009) highlighted high levels of satisfaction within their studies. However, Ku et al., (Ku, Tseng, and Akarasriworn 2013) conducted their study within a blended environment, which typically presents higher levels of teamwork satisfaction than in fully online counterpart (Means et al. 2009; Moskal, Dziuban, and Hartman 2013). This was of interest to the authors as this study arguable reports higher levels of student satisfaction from within a full online environment. Although this could be affected by a variety of different variables within the context of the study, it's a noteworthy finding. Further research examining potential variances due to differing social and educational setting would strengthen future use of this scale.

In addition, participants responded positively overall to the online collaborative attitude questionnaire. This was also a notable finding for the study, as students' attitudes are closely linked with their perception of engineering, motivation to learn, self-confidence, level of competency, performance, and retention in an engineering program (Besterfield-Sacre et al., 1998).

Moreover, this paper outlines twelve elements of successful online collaboration as identified by participants. These elements can be closely linked with the themes and sub-themes presented in the paper by O'Connor et al., (O'Connor et al. 2022). O'Connor et al., (O'Connor et al. 2022) presented six themes and eighteen sub-themes linked to students' perceptions of

PBL in the online environment. Although all elements can be clearly linked to the overarching themes, there are three themes that standout from participant responses. These themes include 1) Communication, 2) Module planning, and 3) Team structure, strength and performance.

Communication has singled itself out within the distance education literature base as a major problem for students when working collaboratively in the online environment (Belanger, Bartels, and She 2021). Many students have reported issues surrounding the ability to communicate effectively with others in the online environment when compared to the traditional face to face environment. Elements associated with communication was a popular topic of discussion for participant. Participants outlined that communication needed to be clear and frequent when working online between both team members and teaching staff. Academics such as Belanger et al., (Belanger, Bartels, and She 2021) outline that students identify fast, convenient and frequent communication as an effective strategy to collaborative work online. However, this isn't a new finding within online learning research. Many other studies have outlined the criticality of effective communication to success within the online environment (Tang et al. 2020). Additionally, participants expected communication to be both synchronous and asynchronous for effective communication to take place within the online environment. Participants also stated that they expected communication to include live face to face elements, such as live lectures on software such as Microsoft Teams or Zoom. Outlining that emails, group chats and other forms of communication lacking face to face engagement are insufficient for effective communication to take place.

Careful module planning is core to teaching and learning process. Module planning provides solid foundation at which teaching and learning can take place. Academics such as Berge (Berge 2002) states that teaching and learning is a social activity that becomes more effective when thoughtful planning and implemented by a facilitator. Elements associated with module planning was also a popular topic of discussion for participant. Participants stated the need for well-defined and well organised instruction to reduce confusion on collaborative tasks, timely resources and frequent instructor support and engagement.

Team structure, strength and performance was the final theme that could be linked to multiple elements outlined from student responses. Participants outlined that they wanted team members to be committed, share clear goals and object and have clear rolls within the collaborative task. Participants also outlined the necessity of team camaraderie

6 CONCLUSION

In conclusion, the findings revealed high levels of student satisfaction and attitudes towards working in teams in the online environment while participating in problem and project-based learning (PBL). This was a welcomed finding for the authors due to it's many links with beneficial outcomes for students. Additionally, the findings outline multiple factors that affect the success of online collaboration. Three of the most prevalent factors being 1) Communication, 2) Module planning, and 3) Team structure, strength and performance. These factors provide a unique student perspective into what affects them, both positively and negatively during an online PBL module. This information can help info future pedagogical decisions both for the authors and readership.

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THE UNDERSTANDING OF BASIC ELECTRICITY CONCEPTS BY FIRST YEAR ENGINEERING STUDENTS: AN UPDATE

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Keywords: *Concept tests, Electricity*

ABSTRACT

The paper reports, analyses and reflects on the results of a multiple-choice diagnostic test to assess student understanding of basic electricity concepts (developed for U.S. high school and college students [1]) taken by nine cohorts of first year engineering students (n=1286) at the authors university, from 2014 to date. The diagnostic test was taken prior to instruction by all student cohorts, and post-instruction by some student cohorts. This paper updates a previous contribution by the author which described the application of the test to seven cohorts of junior engineering students (n=203) from 2008 to 2013. The manner in which this work has influenced instructional methods is outlined.

1 INTRODUCTION

The author has had responsibility for instruction of direct current resistive electrical circuit concepts, over two decades, to cohorts of first year students enrolled on a four year engineering undergraduate programme. Many aspects of direct current resistive electrical circuits are introduced to students in the early cycle of second level education in Ireland, where the author is based. For example, the Junior Certificate Science Syllabus [2], covering the first three years of second level education in the subject in Ireland, advises, amongst other skills, that students on completion of the subject should be able to "set up a simple electric circuit, use appropriate instruments to measure current, potential difference (voltage) and resistance, and establish the relationship between them;" "demonstrate simple series and parallel circuits containing a switch and two bulbs;" "define and give the units for work, energy and

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power, state the relationship between work and power, and perform simple calculations based on this relationship.” These areas are covered well in popular second level books and workbooks (e.g. [3], [4]). These skills are further developed should students study Physics at the Leaving Certificate (the terminal Irish second level examination).

However, in the author’s experience, many students struggle with the topic, with students’ reasoning about basic electrical concepts often differing from accepted explanations. The author has noticed in intensive teaching that this appears to apply to students of all previous educational backgrounds in the topic. This is an international phenomenon, with reference [1], for example, reporting that U.S. high school and university students have similar conceptual difficulties, even after instruction in the subject. These authors supply a 29 question multiple-choice test, which they label the Determining and Interpreting Resistive Electric circuits Concept Test (DIRECT) Version 1.0, to tease out student misconceptions. They assess the test for validity and reliability, and provide detailed data regarding experiences of testing 1135 students, 681 at university level and 454 at high school level. Subsequently, an updated test is proposed [5] (Version 1.1), discussing the authors experiences of testing 692 students, 441 at university level and 251 at high school level. Both tests take 30 minutes to complete. A sample of questions from Version 1.1 of the test is provided in the appendix.

Versions 1.0 and 1.1 of the DIRECT test have been subsequently applied, in pre-test, post-test and delayed post-test mode, with various cohorts of students in second and third level education; space permits mention of only some such examples. At second level, for example, DIRECT Version 1.1, in pre-test and post-test mode, was administered to students in the U.S.A. [6] and Cyprus [7]. At university level, for example, DIRECT Version 1.1, in pre-test and post-test mode, was administered to students in Turkey [8], the U.S.A. [9], and South Africa [10], and was administered, in pre-test, post-test and 11-week delayed post-test mode, to students in Turkey [11].

2 METHODOLOGY

The author requested nine cohorts of students, from 2014 to date, to complete DIRECT Version 1.1 before instruction. These students are enrolled in a common first year of an engineering program, and take the electrical circuits subject in Semester 1. The test was used to identify the nature of student misconceptions prior to material being covered in the lecture and laboratory environment, allowing misconceptions to be addressed. When the opportunity presented itself, the author requested students complete DIRECT Version 1.1 as a post-test immediately after instruction, and/or as a delayed post-test after instruction (at the start of Semester 2). This approach, similar to that applied in [11], allowed an evaluation of whether conceptual understanding of d.c. resistive electric circuits, as measured by the test, improved after instruction, and whether any improvement was sustained.

3 RESULTS

The data from the DIRECT 1.1 pre-test was analysed in two ways.

Table 1 shows the mean percentage test score by the student cohort over nine academic years, with n = number of students who sat the test, and N = number of students who sat the summative assessment in the subject at the end of the semester. Altogether, 1286/1466 or 88% of students sat the DIRECT 1.1 pre-test. Clearly, the pre-test scores for the cohorts of students are broadly similar; it should be noted that, in this multiple-choice test, a mean score of 20% would be expected if students chose the answers to the questions at random. It is clear that, on average, students have poor knowledge of electrical concepts, as measured by this test, as they start their engineering studies. This is despite all students having prior learning in this area at the Junior Certificate level (or equivalent); in addition, though the data is incomplete, it appears that approximately half of the student cohort may have studied Physics at the Leaving Certificate level, or equivalent (in 2019-20, for example, 71 of the 143 students did so). On a positive note, from the data available, a gain in mean post-test and delayed post-test scores is recorded, and is consistent, for the available data, over the period examined. This gain may be linked to the emphasis placed by the author on conceptual understanding in his teaching of the subject over this period. Similar improvements are recorded by Baser and Durmus [11] in their reporting of their use of enquiry learning techniques in the teaching of a d.c. electric circuits course to a cohort of Turkish pre-service elementary school teachers.

Table 1. Mean value of correct answers of some student cohorts

Student cohort	N	Pre-test	Post-test	Delayed post-test
2014-15	165	29 (n=144)	47 (n=109)	*Not done*
2015-16	151	30 (n=146)	49 (n=93)	49 (n=131)
2016-17	196	29 (n=159)	*Not done*	44 (n=164)
2017-18	159	27 (n=118)	*Not done*	45 (n=129)
2018-19	151	29 (n=118)	*Not done*	49 (n=132)
2019-20	143	31 (n=130)	*Not done*	49 (n=129)
2020-21	160	26 (n=162)	*Not done*	*Not done*
2021-22	169	30 (n=169)	*Not done*	*Not done*
2022-23	172	24 (n=140)	*Not done*	*Not done*

Tables 2a to 2d shows how well cohorts of students performed on each of the four instructional objectives that the test was designed to measure, with ‘pre’ and ‘post’ referring to data in pre-test mode, and delayed post-test mode (where available), respectively.

Firstly, twelve questions test understanding of the physical aspects of d.c. electric circuits, asking students to identify and explain a short circuit, test understanding of the functional two-endedness of circuit elements, identify a complete circuit, apply the concept of resistance, and interpret pictures and diagrams from a variety of circuits.

Secondly, four questions test understanding of energy, asking students to apply the concept of power to a variety of circuits, and apply a conceptual understanding of the conservation of energy idea.

Thirdly, five questions test understanding of current, asking students to understand and apply the conservation of current idea, and explain the microscopic aspects of current flow.
Finally, eight questions test understanding of potential difference, asking students to apply the concept of potential difference to a variety of circuits, and to assess how current is influenced by potential difference and resistance.
An example of a question from each of these instructional objectives is given in the appendix.

Table 2a: Mean value of correct answers (in percentage): physical aspects of d.c. circuits

	2014-5	2015-6	2016-7	2017-8	2018-9	2019-0	2020-1	2021-2	2022-3
Pre	38	38	35	35	37	40	29	37	30
Post		68	55	64	66	68			

Table 2b: Mean value of correct answers (in percentage): energy

	2014-5	2015-6	2016-7	2017-8	2018-9	2019-0	2020-1	2021-2	2022-3
Pre	22	22	24	20	20	22	16	24	19
Post		34	38	31	42	38			

Table 2c: Mean value of correct answers (in percentage): current

	2014-5	2015-6	2016-7	2017-8	2018-9	2019-0	2020-1	2021-2	2022-3
Pre	20	23	21	20	23	22	32	24	16
Post		32	34	29	36	34			

Table 2d: Mean value of correct answers (in percentage): potential difference

	2014-5	2015-6	2016-7	2017-8	2018-9	2019-0	2020-1	2021-2	2022-3
Pre	28	29	29	25	27	30	13	28	22
Post		42	36	38	37	39			

Tables 2a-2d reveal consistency in the results from year to year (except in 2020-2021, perhaps because the test had to be done on-line during the COVID-19 pandemic), and consistency between pre-test and post-test results (where available). Clearly, students are most comfortable, both before and after instruction, with an understanding of the physical aspects of d.c. electric circuits. More detailed analysis of the answers to individual questions are available from the author, and will be discussed in the conference presentation.

Previous work done by the author with a colleague [12], with the 2014-15 student cohort, shows a statistically significant correlation ($p < 0.05$) between student spatial ability and the conceptual understanding of the physical aspects of d.c. electric circuits as measured by the DIRECT test, with no statistically significant correlation between spatial ability and the other three instructional objectives of the DIRECT test. This work remains relevant, as engineering graduates tend to have good spatial ability (for example, it has been shown that the majority of Science, Technology, Engineering and Mathematics (STEM) graduates in the USA (n = 400 000) had good spatial skills at age 13 [13]).

Overall, further work remains to be done in enhancing student conceptual understanding, particularly in the instructional objectives where improvement is most required. The author is addressing this in the classroom by concentrating on student learning of fundamental concepts using audience response systems to encourage collaborative learning, with colleagues in the laboratory using enquiry based learning for some activities. In addition, the use of problem based learning has been incorporated in other modules.

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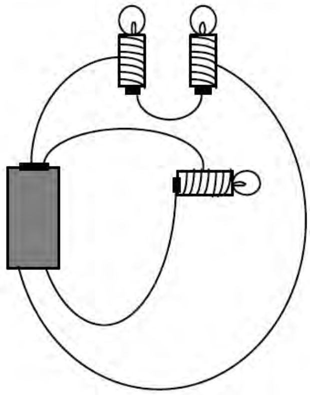
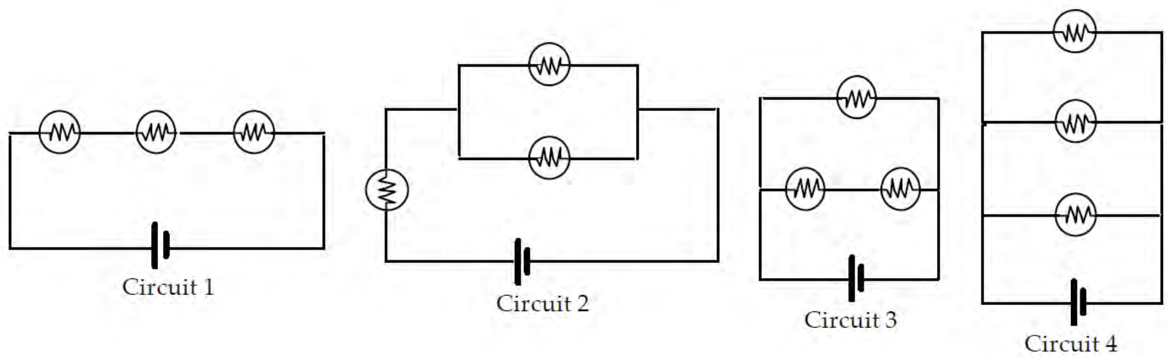
APPENDIX

Instructional objective 1: Understanding of the physical aspects of d.c. electric circuits - sample question

13) Which schematic diagram best represents the realistic circuit shown below?

(A) Circuit 1
(B) Circuit 2
(C) Circuit 3
(D) Circuit 4
(E) None of the above

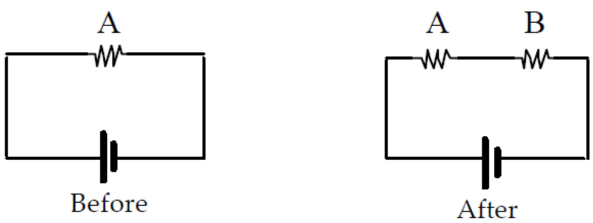




Instructional objective 2: Understanding of energy - sample question

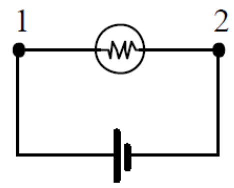
2) How does the power delivered to resistor A change when resistor B is added to the circuit? The power delivered to resistor A _____.

(A) Quadruples (4 times)
(B) Doubles
(C) Stays the same
(D) Reduces by half
(E) Reduces by one quarter (1/4)



Instructional objective 3: Understanding of current - sample question

8) Compare the current at point 1 with the current at point 2. Which point has the LARGER current?



(A) Point 1

(B) Point 2

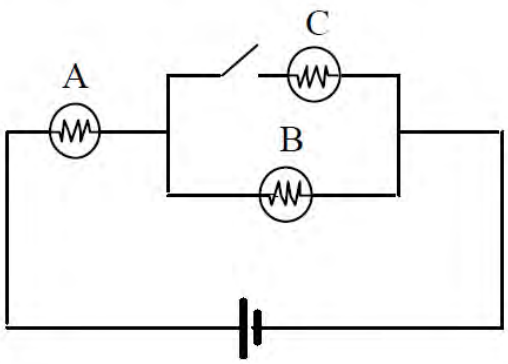
(C) Neither, they are the same. Current travels in one direction around the circuit.

(D) Neither, they are the same. Currents travel in two directions around the circuit.

Instructional objective 4: Understanding of potential difference - sample question

29) What happens to the brightness of bulbs A and B when the switch is closed?

(A) A stays the same, B dims
(B) A brighter, B dims
(C) A and B increase
(D) A and B decrease
(E) A and B remain the same



A NEW APPROACH TO ENCOURAGE THE FUTURE GENERATION OF FEMALE ENGINEERS IN SPAIN: AN INNOVATIVE AND ENGAGING PODCAST: "CLAU, I WANT TO BE AN ENGINEER"

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Keywords: *#womeninSTEM #womeninengineering #genderequality #gendergap #girlsinengineering #inspiringgirls*

ABSTRACT

The underrepresentation of women in STEM fields is a complex issue with multiple factors that remain unclear. At Universidad Politécnica de Madrid (UPM), we have dedicated years to devising strategies aimed at attracting more girls to this domain. As the coordinating institution of the EELISA alliance, where we endeavor to define the European engineer, we confront gender inequality as one of the foremost challenges. To address this need, a 4th year student at UPM conceived an initiative: a podcast with three primary objectives. Firstly, it aims to highlight the accomplishments of female engineers who can serve as role models for girls. Secondly, it seeks to spark the interest of girls in pursuing STEM careers. Lastly, it aims to increase the visibility of current female engineering students. The student discusses engineering in a captivating manner, revealing the fascinating world of STEM. This informal conversation between two women resonates with girls, allowing them to envision themselves undertaking similar paths in the future. The content is readily accessible through popular social networks and platforms such as Instagram, TikTok, YouTube, and Spotify, which are frequented by young people daily. This ongoing project has the potential to significantly contribute to the rise in the number of girls applying to study engineering in Spain.

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1. INTRODUCTION

In the last 100 years women have made important improvements in education and the workplace. There are currently more women than men studying at university in Spain. According to the data presented by the Ministry of Universities (Ministerio de Universidades 2022), in university entrance exams, women represent a higher percentage than men (57,3% in 2020). The percentage of women enrolled in Bachelor's (56.3%) and Master's (54.8%) in the 2021-22 academic year is also higher than that of men. In PhD the percentages of men and women are very similar.

In scientific and technological areas, however, women's educational achievements have been less impressive and their progress in the workplace perhaps slower. The distribution by areas of education is not homogeneous. The participation of women is unsatisfactory in STEM[2] areas. More specifically, at the undergraduate level, men outnumber women in nearly all fields of Physics, Engineering and Computer Science, known as PECS, where the gender imbalances find a dramatic difference.

This underrepresentation of women in engineering studies and careers is a complex issue that has been increasingly studied in literature in the last decade. Various factors have proven to be the cause of this imbalance: gender stereotypes and socialisation, lack of female role models, educational and cultural factors, work environment and bias or lack of awareness and exposure.

2. UPM GENDER DATA

Table 1: Percentage of female students UPM, year 2021-22 by education level

	Male	**Female**	**Total**	**Female (%)**
Bachelor’s Degree	19.893	9.649	29.542	32,66%
Master’s Degree	4.170	2.323	6.493	35,78%
Doctorate (PhD)	1.442	715	2.157	33,15%
TOTAL	**25.505**	**12.687**	**38.192**	**33,22%**

Source: (Universidad Politécnica de Madrid 2022)

3. WHAT DOES UPM DO TO ATTRACT FEMALE STUDENTS?

It is crucial to emphasize that the promotion of gender equality and diversity is a continual undertaking that necessitates sustained, long-term endeavors from both the university and society at large.

At the Universidad Politécnica de Madrid (UPM), we employ a range of strategies aimed at fostering the engagement of female students within our engineering schools. These initiatives can be broadly classified into the following four categories:

1. Orientation and dissemination programs: The UPM organise events, talks and guided tours specifically aimed at secondary and high school students. These programs aim to show them the opportunities and potential of

[2] STEM: Science, Technology, Engineering and Mathematics.

engineering careers, as well as demystify gender stereotypes associated with these areas.

2. Mentoring and tutorials: The university establishes mentoring and tutorial programs where students have the support of female professionals and advanced students in engineering. These women act as role models and provide academic and career guidance, which can help boost girls' confidence and motivation.

3. Participation in external networks and events: UPM participates in conferences, fairs and other events related to the promotion of gender equality and the participation of women in STEM careers. This allows establishing alliances and collaborations with other institutions and organisations that share similar objectives.

4. Awareness and training: The university promotes awareness and training in gender equality among its academic community. This includes training for faculty and staff to eliminate potential gender biases in education and promote an inclusive and equitable environment.

Beyond -and in parallel with- these initiatives, we were looking for a new way to reach those girls born between 2007 and 2013, who are mostly part of what is called Generation Z.

4. WHAT KIND OF PLATFORMS DO OUR TARGET USE?

4.1 The importance of podcasts. Spotify and YouTube.

Generation Z, also known as Gen Z, is fundamentally altering the established conventions pertaining to the consumption and comprehension of information, specifically in terms of how, when, and where it is accessed. This cohort invests considerable amounts of time in engaging with highly personalized social media platforms, which have become their primary outlet for accessing news, information, establishing social connections, engaging in online shopping, and various other activities. A research study indicates that when seeking information regarding restaurants, bookshops, or bakeries, for instance, Gen Z individuals predominantly turn to TikTok rather than relying on search engines or online maps. TikTok has emerged as their preferred platform of choice, serving as the default option for their needs (Oliver Wyman Forum 2023).

Podcasts have emerged as a platform through which members of Generation Z can navigate life's most intricate challenges. Whether they are grappling with significant transitions such as commencing college or entering the realm of employment, or seeking insights on relationships, Spotify stands out as a primary tool facilitating the discovery of such answers through podcasts.

As adolescents develop a broader understanding of life and cultivate their own perspectives, they increasingly find themselves confronted with the task of managing profound emotions. In this context, audio content, particularly podcasts, plays a crucial role in providing essential support. In Spain, over the past year, there has been a remarkable surge in the number of young individuals tuning in to podcasts on Spotify, with an astounding 127% increase during the first quarter of 2022 compared to the preceding year. Presently, more than half (54%) of young people aged between 18 and 24 in Spain listen to podcasts at least once a week, and this figure stands at 32% for those aged between 15 and 17.

According to Generation Z, one of the key attractions of audio content lies in the fact that podcasts provide a secure environment for processing their emotions. Whether they struggle with expressing their thoughts due to shyness or are still searching for the appropriate words to articulate their feelings, podcasts offer a non-judgmental space. In Spain, a notable 64% of young individuals aged 18 to 24 acknowledge turning to podcasts to find answers to personal or challenging questions before confiding in their families. Furthermore, 68% of them reveal that they listen to podcasts as an information source to enhance their conversations with friends. This does not imply that Generation Z avoids deep personal discussions face-to-face, but rather that podcasts have become a valuable complement to their existing communication channels.

This approach aligns perfectly with the underlying purpose of the podcast "Clau, I want to be an engineer," as it resonates with the intended narrative model.

4.2 Social Media: Instagram and TikTok

Our podcast also utilizes social media with a dual objective:

1. To showcase episode highlights: Users may not have the opportunity to listen to the entire podcast, but they can access bite-sized messages encapsulating the key themes we aim to convey. These messages touch upon topics such as resilience, effort, dreams, friendship, curiosity, and enthusiasm.
2. As a means of communication and content promotion: Social media serves as a platform for effectively communicating and disseminating the podcast's contents.

Among Generation Z in Spain, Instagram stands as the most extensively utilized social network. We are currently in the process of familiarizing ourselves with Instagram Reels, wherein interactions are contingent upon the emotional connection with the reel, its dissemination across other platforms, and comprehending an algorithm that undergoes frequent modifications.

In Spain, TikTok garners usage from 28% of the entire population, with the predominant age group being 16 to 24 years old. Within this age range, an impressive 62% of users engage with the platform (Data Reportal 2023). Additionally, the report highlights that TikTok users in Spain devote an average of 52 minutes per day to the application, signifying a substantial level of engagement from Generation Z.

Furthermore, it is worth noting that TikTok is set to introduce a significant change that holds relevance for our podcast. This change involves the implementation of a label or tag specifically designated for videos and programs associated with scientific and technical knowledge—a STEM tag. This feature is already operational in the United States and is anticipated to have a significant impact.

5. HOW THE PODCAST “CLAU, I WANT TO BE AN ENGINEER” IS BUILT

5.1 Justification

Our primary aim is to captivate the interest of young individuals through storytelling. The program's design adheres to the structure commonly referred to as "the Path of the Hero," which draws inspiration from Joseph Campbell's Monomyth (Campbell 2008). Specifically, our focus lies in the journey of embarking on a university education, particularly within the STEM field, encompassing its fundamental principles (Mestas and Close 2019). This structure forms the foundation of our storytelling approach.

The program aims to offer more than just a catalogue of STEM careers at our university; it strives to provide a collection of stories featuring young individuals on their personal heroine's journey, specifically highlighting their experiences within various schools of engineering or architecture. Listeners, particularly young female students, establish a connection between the narratives they hear and their own life paths. They find resonance in shared perspectives while discussing their studies, fears, influences, and most importantly, their conclusions and lessons learned. This journey has led them to a point where they embody the spirit of STEM careers, embracing the motto "learning by making mistakes."

Listeners readily identify or envision themselves within the different situations described in the podcast. They recognize a comprehensive vision of life and the future that is fully developed. The program becomes a personal and intimate story.

The genesis of this program can be traced back to the academic experience of a student from Universidad Politécnica de Madrid, who, after participating in an Erasmus program at Politecnico di Milano (Italy), realized that the existing gender gap was prevalent in both institutions. This realization prompted her to take action, acknowledging that if those of us who are involved and committed do not step forward, who else will?

Upon analyzing various initiatives, it became evident that there was a lack of role models who could provide insights into the academic transition and the overall life experience within STEM fields. The student herself yearned for a program that would elucidate what a STEM career truly entails, how it is experienced throughout the years of study, and how professionals in these fields are perceived. She expressed, "I have not come across a program that informs me about the essence of this degree. If I had known, my fears and uncertainties would have dissipated. How can I ensure that other young individuals are aware of this in advance?"

The transition from school to university typically gives rise to a significant influx of doubts, stress, failures, the need for organization, and the formation of study groups, among other challenges. This journey often leaves students feeling overwhelmed. These considerations have led to the development of a program that aims to provide answers to the very same questions that students like this individual once coped with.

5.2 Podcast structure and duration

Each chapter of the program has a duration ranging from 40 to 60 minutes and encompasses the following structure and topics:

1. The motivations that drive female students to pursue a STEM degree.
2. The influential figures and role models they look up to, including parents, friends, high school teachers, and individuals from whom they sought advice while contemplating this degree.
3. The means through which they discovered the specific degree they pursued.
4. Their initial experiences and challenges during the early years of university.
5. Their preferred modules, seminars, or courses that amplify their motivation.
6. Lessons learned from failures and how they navigate and cope with setbacks.
7. The connections they form with faculty members and classmates.
8. Their aspirations and future projections.
9. Insights they would share with their 15-year-old selves.
10. The mistakes they have made and the valuable lessons they have derived from them.
11. Additional knowledge and skills they acquire beyond the technical aspects of their university education.
12. Their strategies for encouraging young girls to embark on STEM careers.

Each chapter delves into these aspects, providing a comprehensive exploration of the personal journeys and experiences of these young female students pursuing STEM degrees.

5.3 Project description

We have considered two distinct groups of individuals based on their stage of life, primarily because their expectations differ significantly:

1. Young female students at the secondary level (secondary level, baccalaureate) who are yet to enter university. This group seeks to understand the profiles of current university students and aspire to envision themselves in the shoes of those who are nearing the completion of their degrees.

2. Female students pursuing engineering degrees. This group yearns to connect with peers who are undergoing similar experiences and to gain reassurance that the culmination of their academic endeavors will lead to fruitful professional trajectories, akin to the accomplishments achieved by numerous researchers and executives.

With these objectives in mind, we have meticulously devised the following schedule:

Phase 1 – December 2022 – September 2023:

- Conduct interviews with young female students or recent graduates.
- Conduct interviews with female lecturers or professors who serve as role models for our students.

Phase 2 – September 2023 - 2024:

- Conduct interviews with female students.
- Conduct interviews with female lecturers and professors.
- Present research projects.
- Conduct interviews with female scientists and researchers.
- Conduct interviews with female executive directors employed by prominent companies.

Teachers, professors, and other role models play a vital role in instilling a sense of security in current and prospective students. They embody the archetypal "magical character" within the monomyth narrative, serving as guides who equip students with the necessary tools to accomplish their goals. By portraying these role models as ordinary individuals, students perceive them as relatable companions in their educational journey, fostering a closer partnership in the learning process.

6. RESULTS

While it is premature to discuss concrete outcomes, we are pleased to note that the feedback we have received thus far has surpassed our expectations. Our audience has been sending us numerous uplifting messages, indicating that we are making a positive impact on individuals who are navigating critical decisions regarding their professional careers.

Regarding the growth of our presence on social media, it is important to clarify that we have made no investment in advertising. As mentioned, the podcast is divulged through platforms such as Spotify, YouTube, Instagram, and TikTok. A summary of its performance can be observed in Tables 2, 3 and 4.

Table 2: Podcast data from different platforms May 2023

	Spotify	YouTube	Instagram	TikTok
Followers	394	174	753	1.767
Total impressions	3.086	4.377	227.813	544.694
Streams last 30 days	1.499	1.785	50.361	337.894
Streams last 7 days	497	641	8.797	88.846

Table 3: Total followers from February to 10th May 2023

	Spotify	YouTube	Instagram	TikTok
February	129	15	210	0
March	169	42	339	657
April	339	120	509	1.568
May 10th	394	174	753	1.760

Table 4: Accumulated impressions (reach) from February to 10th May 2023

	Spotify	**YouTube**	**Instagram**	**TikTok**
February	987	425	54.686	0
March	1.449	1.624	142.991	69.010
April	2.433	3.400	183.624	445.760
May 10th	3.086	4.377	227.813	544.694

The data indicates a consistent increase in followers and reach across all platforms. There has been a progressive rise in the number of both followers and number of reproductions each month, signifying a growth in popularity or reach on these platforms. TikTok exhibits the highest follower growth compared to other platforms. This suggests that TikTok has proven particularly effective in attracting and engaging with its audience. In summary, the presence on these platforms has successfully attracted and expanded a follower base, with TikTok demonstrating the most notable growth.

7. CONCLUSIONS

EELISA is an alliance of European universities in the field of engineering, technology, and innovation that aims to strengthen and enhance engineering education, research, and innovation throughout Europe. Through collaboration, member universities can combine their resources and expertise to tackle shared challenges and promote excellence in engineering education. One of EELISA's objectives is to develop a unified European engineer profile deeply rooted in society, characterized by enhanced inclusivity, interdisciplinary collaboration, and unwavering dedication.

Promoting inclusivity and addressing the gender gap in engineering is not only a matter of fairness but also crucial for advancing the field. Diversity brings varied perspectives, experiences, and approaches, fostering innovation, creativity, and improved problem-solving. Challenging gender stereotypes and promoting positive portrayals of women in engineering is essential for attracting more women to the field. Showcasing successful women engineers, highlighting their contributions, and dispelling misconceptions about gender and engineering abilities can help reshape perceptions.

Our ongoing efforts to promote inclusivity and bridge the gender gap in engineering involve actively working towards creating a more equitable and diverse engineering community. The podcast "Clau, I want to be an engineer" is one of the most effective tools we have discovered to reach young audiences and it has the potential to significantly contribute to the rise in the number of girls applying to study engineering in Spain.

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FOSTERING A SUSTAINABLE FUTURE THROUGH INCLUSIVE DESIGN

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Conference Key Areas*: Engineering Skills and Competences, Lifelong Learning for a more sustainable world; Equality Diversity and Inclusion in Engineering Education*
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ABSTRACT
Fostering a sustainable future requires a balance between human necessities, societal institutions, and environmental systems; and this delicate equilibrium is best attained through strategic and innovative design. With this, and the growing diversity of our communities, it is imperative to equip engineering students with inclusive perspectives that allow them to critically assess the socio-technical elements of sustainable design. Recent research within engineering education has elevated the importance of empathy as a design practice and inclusivity as a design principle; exploring topics of bias and exclusion are essential to this work. As part of a first-year design course, we introduced these topics in a five-part instructional series, called Leading through Inclusive Design.

This series first focused on identifying exclusions in our designed world and exploring the intentionality of design. Second, students reflected on their identities and considered how biases might influence design work. Next, in the context of a re-design project, students evaluated the

exclusivity of an object and implemented learned strategies toward an inclusive re-design. Finally, by applying inclusive design principles and leadership mindsets, students were asked to develop an 'ecology' of solutions for a Grand Challenge' as defined by the National Academy of Engineering. Solving these multiplex problems around themes of sustainability, health, security, and joy of living required cultural, ethical and economic awareness beyond traditional engineering proficiencies. We describe the implementation of this series and summarize the unique outcomes of our approach for a class of predominant white, male engineering students with diverse majors and passions.

1 INTRODUCTION AND MOTIVATION

Designing solutions for a sustainable socio-technical future will only increase in complexity as we trend toward a more connected and heterogeneous world. This evolution begs design professionals whose qualifications stretch beyond the traditional engineering skillsets (Galloway 2007). It drives a need for expertise in user-centered solutions grounded in principles of inclusive design (ID) and empathetic leadership.

The challenge to engineering educators however, exists in the development and implementation of ID lesson plans. Dong (2010) highlights three such concerns at the course-level. First, the ID lessons should be strategically blended into the curriculum to avoid it being stigmatized as a stand-alone topic. Otherwise, this inadvertently leads students into a skewed view of ID as 'designing for special needs'. This is the second challenge that must be overcome and requires molding ID lesson plans to meet students where they are at, and in real-time if needed. Finally, although the value of real-world, problem-based activities in ID education is evident (Altay et al. 2016, Caswell et al. 2010, Prince 2004), implementation is often limited within a single semester-long course.

To address these needs and challenges, a five-part ID instructional series, referred to as Leading through Inclusive Design (LTID), was implemented inside a year-long design course for first year honors students with interdisciplinary interests. This course, titled Leadership by Design (LbD), hosted projects of varied scales which provided a unique opportunity to overcome some of the aforementioned logistical concerns in ID education. The five-part series was delivered over the progression of one semester of the LbD course.

The LbD course included two sections of 40 students engaged in 75-minute class sections. To encourage active participation in the LTID series, students were broken up into smaller groups depending on the activity. ID education and discourse necessitates a group which is small enough to facilitate all voices being heard but large enough to have the diverse perspectives crucial for the desirable depth of dialogue.

1.2 Our Philosophy and Approach to Designing this Series

We had two distinct goals for this series. As innovators, the learning objective was recognizing that ID practices are critical strategies in creating successful designs. As leaders, the objective was evolving beyond a passive tolerance of diversity education toward active appreciation and productive engagement with a wide variety of perspectives and stakeholders. To facilitate these learning outcomes, we took a distinctive approach to ID education – we shifted the focus from intentionally creating inclusive designs to intentionally avoiding exclusive designs. The former mindset can encourage early-stage students to adopt a ‘check the box’ approach to engineering design practices which often manifest as superficial remedies to accessibility. In the case of teaching first-year students, we focused on avoiding intentional, exclusive design to introduce the topic without having to delve into the complexities of systemic inequities and social constructs surrounding diversity and inclusion. For an upper division course, this tactic could be broadened toward gaining a deeper understanding of unintentional exclusionary practices.

The overall teaching approach was to motivate students to take a critical lens to their current perspectives on inclusivity, and identify how and why it might be relevant to their design work. A combination of active and reflective pedagogies were implemented to achieve this. Reflective pedagogies are critical in strengthening empathic design education to account for inclusivity (Prince 2004). The reflection activities adopted for this series strategically varied in scale of collaboration and degree of guidance. Coupled with these reflective exercises were self-driven learning opportunities rooted in active learning pedagogies. These types of activities were mainly discovery- and problem-based exercises as elucidated by Catteneo (2017).

2 IMPLEMENTATION

The themes of each of the five lessons of the LTID instructional series are described in **Table 1**.

	Session Topic	Description	Reading or Supporting Literature
Part 1	Brave Space Setting	Setting norms/expectations for engaging in this work and motivating the importance of ID in successful design	Brave Space (Brown, 2008)
Part 2	What is Inclusive Design?	Identify exclusions in our designed world and considering the intentionality of design.	Mismatch – Chapters 1 and 8
Part 3	Who is the designer?	Reflect on individual identities and consider how ones biases might influence ones design work.	Mismatch – Chapters 1 and 8
Part 4	Who is advantaged/ disadvantaged?	Evaluate the exclusivity of a chosen object and identify/ employ design strategies toward and inclusive re-design.	Mismatch – Chapter 7
Part 5	Who is the design for/with?	Assess the socio-technical elements of an engineering grand challenge and derive solutions using the learned inclusive design principles and leadership mindsets.	Mismatch – Chapter 5 and 6

Table 1: Structure of the Leading through Inclusive Design instructional series which is anchored by readings from Mismatch: How Inclusion Shapes Design (Holmes 2020)

Mismatch: How inclusion shapes design by Kat Holmes (2020) served as a foundation for structuring reflections and preparing students for the in class discussions. The pivotal concepts from each reading are summarize below.

- Parts 2 and 3 – Chapter 1 introduced the concept of mismatches in design and the idea that inclusion should be an ‘intentional choice rather than an accidental harm’. Chapter 8 provided real examples of how ID motivates innovative design.

- Part 4 – Chapter 7 introduced the human spectrum which spurred reflection on how human beings differ and how biases might impact design

- Part 5 – Chapters 5 and 6 motivate the ID mindset of 'designing with not for' and provides tangible strategies toward ID.

In addition to these preparatory readings which stimulated curiosity, we attribute the successful depth of dialogue attained in this series to instructors' facilitation/engagement as equally curious students of ID. We pushed ourselves to be vulnerable in sharing our experiences and participated in group dialogue by both provoking ideas and allowing our ideas to be challenged. While some discussions were guided, many were impromptu and propelled by student-to-student dialogue.

2.1 Part 1- Brave Space Setting

Part 1 was hosted within a subdivided class session of 20 students. We first provided context for the instructional series with respect to the general LbD coursework/projects and then proceeded to introduce the concept of a 'brave space' in which the lessons would be facilitated.

Brave Space Contracts

To lay the groundwork for a critical exploration into ID, our first exercise was to establish the classroom as a 'brave space' (Brown 2010). As opposed to a 'safe space' where the area is intentionally free of judgement and contention, a 'brave space' is one in which we accept that the necessary conversations might be difficult for some, yet we engage with the dialogue in the interest of education and innovation (Brown 2010). Brave spaces encourage civil discourse on challenging topics with respect and intentionality as drivers beyond empathy and compassion. Both types of spaces offer key educational benefits. Here, we chose to focus on brave spaces to allow students to challenge one another, and their own preconceptions about inclusivity with an eye on critical analysis and depth over comfort.

We established 'rules' of our brave space by having students create social contracts at their shared tables. We encouraged them to sit with their closest peers at the start of this series. In these agreements, we asked them to share how they intend to abide by the expectations of their brave space and get specific about the practices they will implement. Throughout the series we would remind students of these agreements.

2.2 Part 2: What is Inclusive Design?

Coupled with a Socratic discussion on the assigned Mismatch reading, a discovery-based activity of common-place objects successfully introduced the idea of ID and motivated its relevance at depth.

Object Exploration: The World Around Us

The intended goal of this activity was to motivate ID principles as critical tools toward successful design. Allowing students to sit with their peer groups, we placed one of 6 objects on each table: an Xbox controller, an Amazon Echo, a pack of Band-Aids, an automatic soap dispenser, a computer mouse, and an Apple watch. On butcher paper, students were asked to sketch out the matrix shown in **Figure 1** and fill out the quadrants based on the object at their table. Following this, they would rank the object on the inclusivity scale below the matrix. Finally, in silence and individually, students walked around to the different tables, reflected on the groups' assessment, and marked their own ranking on the inclusivity scale for each object. In the initial groups, students then reflected on the assessments thinking about how their evaluations may have differed from the random individual perspectives. We also introduced and discussed popular examples such as the male-biased seatbelt design, and the exclusive nature of facial recognition software toward persons with Asian features.

Key closing conversations of this part were motivated by the following four questions: “Were the designers intentionally, or unintentionally being exclusive?”, “Is it possible to have a design that is 100% inclusive?” and “How might we attempt to avoid being unintentionally exclusive?” Some students made an immediate connection to questioning their implicit biases which motivated Part 3's lesson plan.

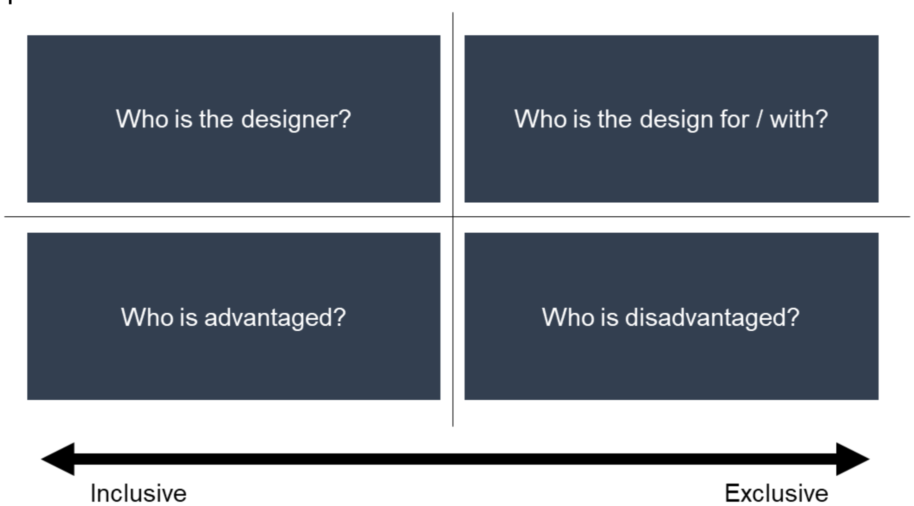

Figure 1: Rubric for Object Exploration Activity and key communication tool for topics to be explored in the LTID series

2.3 Part 3: Who is the Designer?

Using the rubric in **Figure 1** as a communication tool with students, Part 3 of the series concentrated on the upper left quadrant – exploring the identity of the designer and how/why they might influence the success of ID.

<u>Implicit Bias Test</u>

The implicit bias test was assigned as a preparatory class activity. Students were tasked with exploring Harvard's Implicit Association Tests (IAT) (Greenwald, 1998) and completing any two of their choice. We asked that they reflect on the results and contemplate on whether they learned something new about themselves. At the beginning of the lesson, we invited students to share their learnings and perspectives with the greater class.

<u>Biased by Association</u>

Following this, we introduced the notion of human identities and led a guided exploration into understanding biases as implicit products of our experiences and associations. We reflected on whether the biases are inherently good or bad, and whether our biases align with our values. The intended learning outcome was that while we might want our design work to be steered by our values, our implicit biases can unconsciously affect the process and result. Such introspection and personal reflection were critical pre-cursors for the design sprints and discussions that followed in Parts 4 and 5.

2.4 Part 4: Who is Advantaged/Disadvantaged?

Part 4 dug deeper into the lower quadrants of **Figure 1**. Activities in this portion were intentionally aligned with helping students implement ID principles in an object re-design project that was an assignment of the LbD course. As an introductory exercise to this part (taught almost a month after Part 3), students were asked to recall the discussions on bias, imagine who might have designed their object and speculate on the designer’s motivations. They were then asked to reflect on how their biases might influence their redesign work for the project before diving into the following active learning exercises.

<u>Cards for Humanity</u>

Cards for Humanity is an online card game by Eva Tkautz, a member of the frog design team within the creative consultancy Capgemini Invent (Eva 2012) that challenges designers to consider a diverse range of perspectives and user scenarios. Two decks of cards each describe a user and a diverse need. Examples include a person who: is confident and has an essential tremor, is impatient and anxious, is impulsive and listening to loud music, and is very caring and partially sighted. The students utilized these cards to help them imagine how inclusive their objects might be for various people. Students were challenged to explore the following questions for each scenario:

1. In what scenario is this user interacting with the object?
2. What is the user’s goal with this object?
3. Is this object a match or mismatch for this user?
4. If a mismatch, what might an inclusive re-design look like for them?

<u>Object Exploration: Our Object Redesign</u>

Like the activity in Part 2, students used the rubric in **Figure 1** to explore the inclusivity of the object they had selected to re-design. At this point in the LbD course, students were familiar with thinking of successful design in terms of form, function, the systems it interacts with (political, social, environmental, etc.), and its life cycle. With this activity, students further developed this definition of successful design to include inclusive principles. They were able to incorporate issues of accessibility, identity, and diversity into their redesign concepts.

2.5 Part 5: Who is the Design For/With?

Part 5 of the LTID series explored the final, upper right quadrant of the inclusivity rubric in **Figure 1**.The problem-based activities in this section were facilitated by the Global Challenges final group project of the LbD course. The National Academy of Engineering identified 14 engineering Grand Challenges within themes of sustainability, health, security, and joy of living. These complex, real-world design problems with real stakeholders, provided a landscape for us to explore strategies of empathetic design. Leaning on the perspective taking skillsets that were developed to this point in the series, students derived research questions and identified practical tools toward ID.

Identifying Empathetic Tools toward ID

We introduced the idea of empathetic design through design failures, citing published examples of visually impaired and handicapped design (Thomas and McDonangh 2013). Connecting these failures to assumptions made in the design process motivated the need for empathy in design. We used Brené Brown's RSA (The Royal Society for the Encouragement of Arts, Manufactures and Commerce) short video on empathy (Brown 2021) to introduce and define the term. From these discussions, we established that there was a third element of successful design beyond form and function and that is, feeling. The emotional connection that a user makes with the product is the root of empathetic design principles. We briefly reintroduce in discussion, the products of Part 2 such as the Band-Aid. Although successful in terms of form and function, the mismatched 'feeling', driven by the lack of skin color representation, makes it a controversial design.

Reflecting on these stimulated concepts, the question was then posed: "How could the designers of these products introduce empathy into the design process?" Students generated ideas such as having a diverse group of designers, interviewing end users, engaging with the extreme ends of the persona spectrum, and conducting research beyond the technical elements of the solution. As we progressed through this activity, students were challenged to consider how empathetic design shifts the mindset of ID from designing 'for' some user to designing 'with' a stakeholder.

Identifying Research Questions toward ID

Provided the time constraint of their Global Challenges final project, we focused on introducing research techniques as an empathetic tool toward ID. Within their project groups, they were first asked to frame a research question using the format: "How might we [tackle this problem] with [these stakeholders] to achieve [this solution]".

Next, as a group, they were tasked with mapping out three socio-technical elements of their global challenge: the system it is a part of (considering institutions such as social, political, environmental etc.), the stakeholders involved and its historical evolution.

To facilitate this, as a class, students generated a list of actionable research questions to stimulate a deeper level of investigation. A few of these crowd-sourced questions included:

- Where does the challenge exist? (country, specific area, environment)
- What makes it bearable or worse?
- What is the history of the grand challenge? Who has worked on it previously?
- Who are the stakeholders and what is the demographic/identity distribution?
- Why do we personally care? How has it been broadcasted societally/culturally?
- Who continues to benefit/suffer if we do nothing?

These questions were documented and left visible on the board for project groups to reference as they proceeded to complete the three socio-technical maps.

3 RESULTS AND FEEDBACK

Throughout the series, student written reflections (submitted as pre- and post-class assignments) provided real-time feedback. We also formally collected commentary at two instances. Prior to starting Part 3, we provided three prompts for students to quickly answer on index cards: What were their key takeaways thus far? Did they have any habits or pre-conceived ideas that were challenged by the discussions? What might they change as we move forward in the series? At the end of the course, students were asked to voluntarily complete a survey in which they ranked the success of various activities and left comments as they saw fit.

3.1 Regarding Open Discussions

There was overwhelming positive feedback on the open discussions throughout the series which we attribute to three main factors: the setting of the 'brave spaces' before each lesson, the pre-class reading assignments from Mismatch which aroused curiosity and prodded contemplation, and the vulnerable participation in discussions by the instructors. Reflections such as *"I loved the quote in which it states "Always remember that you are unique, just like everyone else." ... How can design be centred around "normal"… how is that possible when we are all different. Normal is a fantasy thus it shouldn't be the baseline for design."* and *"The class discussions were a little tense and uncomfortable (but this doesn't necessarily mean they should be removed)"* are great indicators of the depth of introspection we were able to achieve and the effectiveness of the brave space model for engaging students. The second student quoted above ranked these discussions at the highest level of success on the feedback survey.

3.2 Regarding Exploration of Individual Biases

The IAT activity was less effective than we anticipated and could be replaced with a more in-depth exploration of individual identities and biases. After taking the IATs, student discussion focused on feeling 'tricked' by the questioning which generated a lot of doubt in the results and hindered genuine reflection on their biases. *"I would have greatly appreciated digging deeper into the implicit biases portion of the series."* While some students, were wanting to 'dig deeper', the large group of particularly early-stage students proved to be a challenge for brave space setting and was not conducive for vulnerable discourse. That said, self-reflections submitted after class revealed that students did connect with the material and the learning outcomes were achieved.

3.3 Regarding Active Learning Pedagogy

<u>Object Exploration</u>

The object exploration activities of Parts 2 and 4 were favourites based on the feedback survey. The use of common place objects in Part 2 had a particularly unique outcome in cultivating a deeper appreciation for diversity in a white, male dominated classroom. The Colorado School of Mines has a majority white (68.3%), male (68.3%) population (Diversity, Inclusion, and Access Committee 2022). The LbD course remained true to the gender distribution and had a significant number of white students (80%). For the following students, the activity challenged their perspectives and revealed the hidden 'mismatches' of the designed world.

"It was unexpected just how exclusive many designs are. From male crash test dummies only being used up until recently, or the soap dispenser's blindness towards dark skin, my perspective shifted due to these examples and made me really want to be intentional with inclusivity rather than leaving it up to chance."

“The perspective that challenged my views the most were from students of color who expressed that they did not really care about certain design choices [such as the Band-Aid color] as long as the object was functional.”
“I realized that I struggled to think far outside my background and this challenged my thinking about inclusivity”

Cards for Humanity
For the following students, the Cards For Humanity was a tangible tool that assisted them with perspective taking as they re-designed their objects. Many reflections mentioned realizing that accessibility and price were not the only barriers to inclusivity.
“I loved trying to find solutions for different people and recognizing that there are solutions that already exist for mismatches I had never considered."
“The way some of the cards were not the obvious blind or deaf, but colorblind and stuff made it a lot more nuanced and opened my eyes to it.”

Identifying Empathetic Tools and Research Questions toward ID
As one student aptly reflects, *“Design is not always purely logical. People’s emotions and perceptions should be a huge consideration in the design process.”* The investigation of design failures was a successful, light-hearted approach to introducing a potentially triggering topic of empathetic design. It was well suited for the early-stage student demographic. The strategy of student-led questioning and brainstorming in these activities were also definite victories over lecture-style delivery. This is evidenced by the following student’s attestation.
“In the past, I felt like research on a problem could only get me so far in the design process, and I didn't really value intensive research on problems. Through our inclusive design series, I saw how that research could be empathetic training on the subject rather than being limited to researching prior solutions. It helped me to see how spending time on design in that way was beneficial to my design.”

4 CONCLUSIONS AND SUMMARY

Introducing ID principles in engineering education is an imperative toward building a sustainably designed future (Holmes, 2020). The LTID instructional series approaches this challenge by empowering students, as leaders, to capitalize on the strengths of diversity in their design work. Noting the development and implementation challenges that many educators have faced in introducing ID principles in the classroom (Altay et al. 2016, Caswell 2010 and Dong 2010), we embedded this series within an established first-year engineering design course, LbD.

LTID was successfully structured such that the activities facilitated student process work as they tackled the major design projects of the LbD course. Integrating the ID lessons across active design projects helped students appreciate ID as an essential part of successful design. Students discovered that bringing in multiple perspectives in research and in the interventions that they designed, led to more sustainable and synergistic solutions to the grand challenges.

Our approach achieved successful outcomes in a class of 80 first-year, engineering students with little race and gender diversity but strongly varied societal interests and interdisciplinary degrees. As evidenced by student feedback, the instructional series not only motivated ID principles as tools toward successful design but did so by cultivating leadership mindsets which fundamentally celebrate diversity and equity.

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ENGINEERING SOLUTIONS FOR A MORE INCLUSIVE SOCIETY: A CASE STUDY WITH EUROPE-WIDE CHALLENGE-BASED LEARNING

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ABSTRACT

Engineering practices directly impact our society and yet, traditional engineering courses often present a lack of emphasis on social and sustainable responsibility. Therefore, a course was designed to increase societal awareness and promote social-conscious engineering practices, and also interdisciplinary and intercultural

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collaboration. The course followed the concept of challenge-based learning (CBL) and was offered within the framework of the European Consortium of Innovative Universities (ECIU). In such framework, students from 13 European partner universities could join, as well as professionals and citizens as so-called continuous learners. The challenge addressed the issue of an increasingly aging European society and the physical hurdles brought by aging. In cooperation with a local senior citizens' residence, the participants of the challenge identified everyday challenges in dialogue with senior citizens, and jointly developed 3D printed solutions for such. The article deals with the conception and the accompanying reflection throughout the project. Students were asked how they evaluated the CBL course and how they reflected on the development of their social awareness. Based on the "mixed-method" approach, data were collected, analysed and evaluated with questionnaires (pre- and final survey) and student reflection questionnaires at milestones meetings. This paper emphasize on students' experiences, obstacles and teamchers' solutions in all three CBL phases, just despite the final event and evaluation.

1 INTRODUCTION

The population of elderly people in Germany and the EU is expected to increase significantly in the coming years (Statistiches Bundesamt 2022, European Commission 2020), leading to various challenges related to mobility, vision, hearing, and balance. While there have been efforts to develop technical aids to help seniors cope with these challenges, their widespread application has been limited due to a lack of user-centered design and affordability (Baldewijns et al. 2015) although it is known that user testing and user-centered design are critical to the success of technical systems (Czaja and Sharit 2009). There is a need for a more socially-conscious engineering environment that involves seniors in the development of customized, sustainable technical aids to promote their independence and well-being. So, to develop professional social responsibility is key in modern engineering education (see Bielefeldt 2018). Interestingly, the author found that some elements of engineers' professional social responsibility is widely agreed upon like the protection of the environment, but others vary across countries and disciplines and may decline over time. Bielefeldt also stated that "personal motivation to help others through the application of one's engineering skills can be fostered through a cycle of engaging in this helping behaviour." (Bielefeldt 2018, p.51). Thus, challenge-based learning was selected as potentially appropriate participative and engaging format to foster social conscious engineering education practice.

In contrast to other high-impact engineering education practices like CDIO (Doulougeri et al. 2022), problem-based or project-based learning (Sukackė at al. 2022) or even research-based learning (Healey and Jenkins 2018), CBL is a pedagogical approach that encourages active learning and collaboration to solve real-world challenges in three phases: (1) Engage, (2) Investigate, and (3) Act (Hamburg University of Technology 2023). In the engage phase, participants are introduced to the big idea of the challenge and find essential questions. In the investigate phase, participants identify guiding questions, activities and resources and analyse its potential solutions. Finally, in the act phase, participants develop and implement their solutions and reflect on the outcomes. Various aspects have been recently detailed elsewhere like teacher-student interactions in CBL (Doulougeri et al. 2022), the role of external partners in CBL (Mayer at al. 2022), engagement beyond the classroom (Jimarkon at al. 2022), student motivation (MacLeod et al. 2022) or teamwork influencing factors (Mesutoglu and Bayram-Jacobs 2022).

Considering other CBL practices, experiences and research, this challenge-based learning course aimed at educating engineering students from different countries and disciplines on social responsibility and engage seniors in the development process of technical aids. These were 3D printed out of sustainable materials using direct writing method, thus producing and presenting customized technical aids that meet individual needs. By accompanying the course, the outcomes and training of engineers and seniors with stronger social awareness were documented.

So, this paper initially emphasizes the presented challenge regarding socially-conscious engineering practices. Subsequently, the methodology for evaluating the challenge based on participant responses is introduced. Following this, the results section encompasses the evaluation outcomes, along with the obstacles and solutions encountered in implementing CBL throughout all phases. In conclusion, the findings are summarised and clear directions for future investigations are provided.

2 METHODOLOGY

2.1 This Challenge

This challenge took place over the period of one semester (3,5 months) and covered a workload of 3 ECTS (approx. 90 hours). Thus, this challenge was referred to the type mini-challenge.

In this CBL course, the challenge provider was a locally-based senior citizen's residence together with the challenge hosting university, the Hamburg University of Technology (TUHH). The 14 participants were international and interdisciplinary students and one continuous learner from four European universities collaborating with seniors and the two so-called "teamchers" from TUHH. Teamchers are here researchers and teachers in the discipline of materials engineering and natural sciences. Importantly, teamchers act in their role of facilitating a working team, providing the general structure, supporting in organizational and communication matters rather than providing continuous disciplinary expert support (see Imanbayeva 2021). Due to the large distances between the different universities, the course was designed as a hybrid course. In average, 7 participants joined on-campus of the hosting university and 7 attendees participated online only.

The challenge focused on developing engineering solutions to enhance the quality of life of seniors in the residence. The learning goals of the CBL course included: (a) identifying and analysing societal challenges related to ageing, (b) developing and testing engineering solutions to address these challenges, (c) enhancing critical thinking and problem-solving abilities through a human-centered design approach, (d) gaining experience in collaboration and teamwork, (e) strengthening confidence and communication skills through presentations and discussions, and (f) understanding and reflecting on concepts of inclusivity in engineering solutions and their impact on society through participatory engagement.

Throughout the CBL course, participants have been responsible for developing their own challenge tackling approach and solutions while being supported by the teamchers. The teamchers primarily attended the challenge meetings on campus, i.e. in person, while also providing online access to facilitate a hybrid learning experience. Fig. 1 depicts the time schedule of the challenge. The preliminary meeting took place April 07, 2023 and the closing event on July 11, 2023.

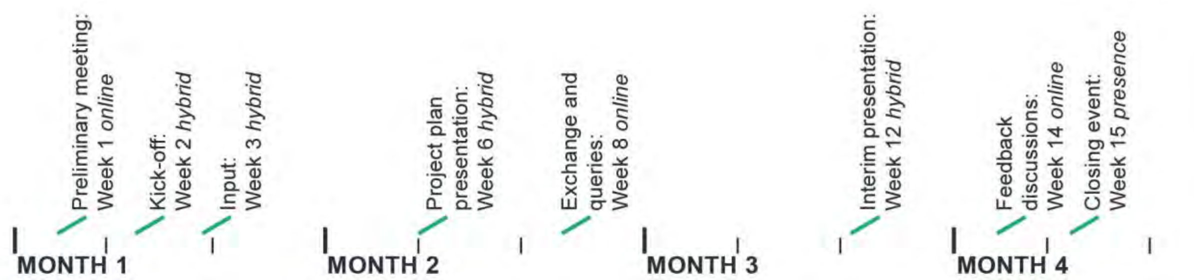

Fig. 1. The time schedule of the CBL course.

In TUHH's WorkING Lab's maker space, hybrid milestone meetings were held (see Fig. 2). The course began with a preliminary meeting for introductions and initial organisational issues. A week later, the senior residence staff introduced themselves at a kick-off meeting, and participants were divided into teams for brainstorming and team building. The next week involved an input meeting, providing teams with key information about 3D printing capabilities (see Fig. 3), project management, user-centered design, and ethical collaboration with seniors.

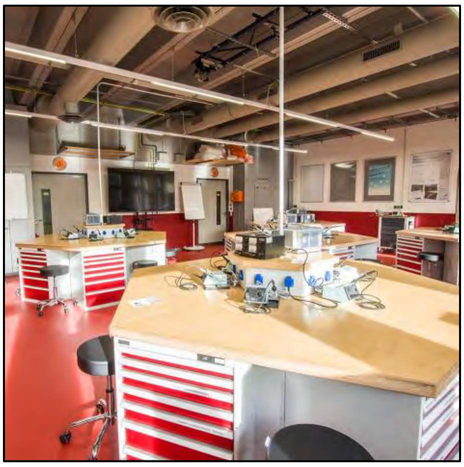

Fig. 2. Maker space for hybrid sessions

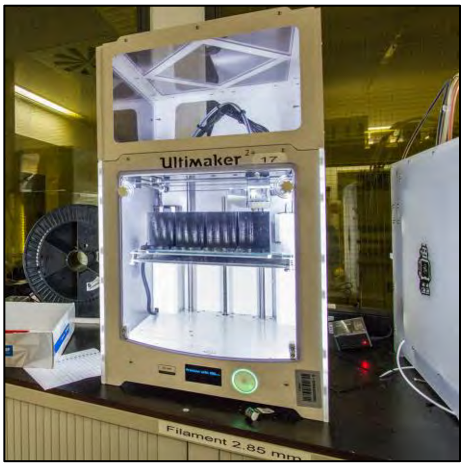

Fig. 3. 3D printer used in this challenge

In addition to these meetings, presentation meetings were held where the teams presented their project plans and later on their interim results. A feedback discussion was held at the end of the work period, followed by a public closing event where prototypes of aids for seniors were presented and demonstrated. Surveys were conducted at the end of each milestone meeting to provide insights into group dynamics and working progress. In addition to the milestone meetings, teams also held self-organised team meetings and meetings with seniors, with the latter being supported by senior residence and university staff. During these meetings, teams engaged in dialogue with different seniors about their challenges and potential aids to improve their daily lives.

2.2 The Evaluation

We aimed here to explore how challenge participants engaged in the challenge, reflected on their experience, and evaluated their development of social awareness in their engineering practices. To address these questions, we adopted a mixed-method approach. Data were collected using three self-designed questionnaires on Limesurvey: a pre-survey (7 items, mostly free text boxes). Four reflection surveys along the project progress, i.e. at the end of the milestone meetings, i.e. kick-off, input, project plan and interims presentation (9 items with 6 on a 4-point scale and 3 free text boxes), and a final evaluation after participants completed the course (17 items across three levels of evaluation according to Kirkpatrick and Kirkpatrick (2006): reaction, learning, and future perspectives, as well as recommendations). Especially the reflection surveys offered to submit the responses to the teamchers, but allowed to disagree on publication which decreases the number of responses. We analysed the data using descriptive statistics. Additionally, just one week before the closing event, we held an oral feedback discussion meeting where the two project teams used a flinga board and were asked separately to reflect on their work within the teams, the teamchers and collaboration with the seniors in terms of what they appreciated, which obstacles have been tackled in which way and which hurdles are still open to be solved.

3 RESULTS

3.1 Evaluation Results

The first evaluation results presented here include results of the pre-survey, all four reflection questionnaires and the feedback meeting. These highlight students' experiences in all three CBL phases, despite the closing event combined with the final evaluation.

Pre-survey: The results of the pre-survey indicate that the six respondents were motivated and had realistic expectations upon entering the challenge. Most respondents found out about the challenge through the E-learning platform of TUHH among other sources. Respondents joined the challenge with the aim of contributing to society and practicing 3D printing. They identified losing team members, a tight study schedule, and the hybrid format as hindering aspects, and dedication to the challenge as a facilitating factor for achieving the challenge goals. Finally, they expressed their excitement and appreciation for joining the challenge.

First reflection: At the first reflection, collected at the end of the kick-off meeting, nine respondents found the meeting to be very positive, feeling well accepted in the project team and motivated. Respondents were satisfied with the first results so far, confident in developing great prototypes, and knew what was expected of them. Their personal “Highs” included teamwork and brainstorming sessions, while their personal “Lows” related to technical issues and adapting to the hybrid format. They highlighted the need for organisational and communication support and clear expectations on the goal, product, and specified tasks to start working in their teams.

Second reflection: The second reflection was collected at the end of the input meeting, where seven respondents reported a positive experience in the meeting. Their main feedback did not change significantly, but only three respondents felt well accepted in the team. Their “Highs” included understanding various input topics within a short time, controlling enthusiasm and expressing their opinions in the group. Their “Lows” related to becoming familiar with digital tools and staying focused, particularly when discussing topics of which they had prior experience. They stated that they have learned about 3D printing, understanding the right problem statement, planning team meetings, sorting out their own schedules, helping the elderly, and studying hard to achieve success. They mentioned that the next steps are to work in their teams.

Third reflection: In the third reflection, collected at the end of the project planning meeting, ten respondents reported a positive meeting experience. Especially, the team acceptance, satisfaction and motivation was detected as very positive while participants’ confidence was positive and the expectations have been clear, but not completely. Their “Highs” related predominantly to meeting, talking and listening to the seniors and building a relationship and experience seniors’ interest as well as to conducting the project better within time and using management tools, to present the project and getting feedback and to conveying all ideas. The respondents identified their "Lows" as deficiencies in certain communication skills (with seniors, presenting their projects, and giving feedback), articulating the problem statement, and using the design software. To move forward, respondents described to need a clearer understanding of the seniors’ problem, a selection of one problem to be focused on, a vision of a prototype that can be produced in the available 3D printer, team work and collaboration with the second team, feedback and motivation.

Fourth reflection: In the fourth reflection, only 4 participants responded at the end of the interims presentation. Interestingly, for the first in this challenge, one respondent mentioned lower satisfaction and confidence. The reported “Highs” in this phase relate to making prototypes and talking to the seniors and care takers to gather more information. “Lows” that have been stated relate to not being able to make 3D prints yet and time management. To move forward they stated to need more communication with seniors, expert input on 3D drawing and dedicated time to work on this challenge by all team members.

The reflection meeting: 12 participants joined the reflection meeting which was held one week before the closing event, i.e. at the very productive finishing phase of the challenge. The participants appreciated the access to the input resources via padlet, used media in the meetings and the WorkING Lab facility, the availability, clarity in expectations and organisational support by the teamchers, the enthusiastic and sharing team atmosphere and productive work within their teams as well as the relationship with the seniors. They stated that their learning relates to a structured project work including manufacturing techniques/ 3D printing, management roles, tools and the opportunity to get in contact with product end-users as well as helping the society. Finally, they shared that they experienced obstacles related to arranging team apointments, decision-making process in their teams, expert knowledge on 3D printing, 3D printing limitations. In that last week, their challenges relate still to communicate with all and make fast and democratic decisions on key prototype design aspects or shortly test the prototypes with the seniors for modifications for the final printing - all while participants are busy with other projects at the end of the semester.

3.2 Obstacles and Solutions in Conducting the Challenge

During the planning of the course, the authors have brainstormed the potential obstacles for the successful development of the ECIU course (such as obstacles 1, 2 and 5), but also collected further information from the surveys' results detailed in section 3.1., which allowed the identification of further obstacles, as well as confirmation of expected ones. A detailed description of each obstacle and their solutions is provided below.

Obstacle 1: Hybrid format - Solution 1: The challenge-based learning course faced the challenge of organising teams comprising participants from the challenge hosting university (TUHH) and students from other European universities, as well as conducting meetings in a hybrid format. To overcome this obstacle, teams were mixed. So, each team included students that participated online as well as in-person at TUHH's campus. Information and updates were shared on a Padlet, and email communication was encouraged. Nevertheless, the student teams themselves had the freedom to decide on the communication channels to be used. Additionally, presence meetings were planned, involving online and on-campus participants. For such events, students could apply for financial support from their home institution for personal traveling.

Obstacle 2: Different scales of pre-knowledge, especially on 3D printing - Solution 2: To tackle the varying scales of knowledge and experience, especially with 3D printing, team building was integrated in the kick-off meeting to mix the teams accordingly to their previous knowledge. Moreover, broad impulses were given in the input meeting (3D printing, project management tools, user-centered design, partnering with seniors), as a mean to level the knowledge and bring the ones without previous knowledge to be able to interact and contribute. Also the teamchers referred to 3D experts within the hosting university when advanced technical competencies where needed.

Obstacle 3: Desire for clear expectations - Solution 3: The participants expressed the need for clear expectations in terms of decision making and the role of the teamchers in the CBL course. To address this, the teamchers explained their own and the participants' role and the teams' autonomy in decision-making processes in the course, while also providing clear expectations for the students throughout the challenge.

Obstacle 4: Making team decisions – Solution 4: To handle a lot of ideas that came up in various project phases, the teams used voting in meetings and messenger services as a democratic, inclusive and effective decision-making method. Especially, the feedback meeting in the last week with the teamchers helped that the teams reflected their options on finalising the prototype and go with one decision that meets the expectations and increased confidence in the final prototyping.

Obstacle 5: Language restrictions - Solution 5: Language capabilities are a key in this challenge, so that participants could properly communicate with the elderlies. The CBL course involved participants from different countries, with language knowledge differing from that of the elderlies. To overcome this, participants were distributed so that each team contained at least one person, whom would speak the same language as the elderlies. Additionally, the teamchers offered to assist with translation in meetings with the elderlies which turned out not to be necessary.

Obstacle 6: Arranging appointments for team meetings – Solution 6: Teams decided to arrange a couple of hybrid meetings in advance and take detailed notes to enable that participants who could not join are still up to date.

Obstacle 7: Limited prototype design with 3D printing technology – Solution 7: To overcome design restrictions that are related to the 3D print technology, one team decided to modify the prototype and thus, buy one part of their assistive technology and design only the other part by using 3D printing. The other team decided to design a simple, but effective assistive technology that can be completely printed.

4 SUMMARY AND ACKNOWLEDGMENTS

This study introduced a CBL course designed to foster intergenerational cooperation and to confront aging-related challenges through engineering solutions. Our CBL approach elevated social awareness in engineering students by incorporating seniors' experiences and promoting the use of 3D printing with sustainable filament. Evaluation results suggested that the course successfully facilitated collaboration and the development of a socially conscious perspective.

In accordance with the literature (Jimarkon at al. 2022, MacLeod et al. 2022), our study demonstrated that CBL allowed participants to navigate various experiences, from "Highs" to "Lows", fostering complex learning and increased awareness of daily aging issues. This is a crucial outcome as it motivates students to contribute socially and professionally to societal challenges (Bielefeldt 2018). While our findings are limited by methodological factors and the number of participants, they indicate that our approach was effective. However, we are unable to definitively state if our method was superior to other potential approaches.

Moving forward, we propose several steps: (1) gathering final evaluations from student participants, (2) procuring feedback from the partnering senior residency, (3) drawing a comprehensive conclusion from this challenge, and (4) creating practice guidelines for future collaborations with seniors within a CBL framework. These steps will shed light on the potential of such practices and contribute to a database of CBL implementations, inspiring future similar challenges. By sharing our experiences, we hope to encourage the use of CBL in addressing societal challenges across generations. Furthermore, our experience may provide useful insights for other institutions looking to integrate similar strategies into their curriculum.

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ETHICS4EU: DESIGNING NEW CURRICULA FOR COMPUTER SCIENCE ETHICS EDUCATION: CASE STUDIES FOR AI ETHICS

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ABSTRACT

The computing ethics landscape is changing rapidly, as new technologies become more complex and pervasive, and people choose to interact with them in new and distinct ways. The resultant interactions are more novel and less easy to categorise using traditional ethical frameworks. It is important that developers of these technologies do not live in an ethical vacuum, that they think about the consequences of their creations, and take measures to prevent others being harmed by their work. To equip developers to rise to this challenge and create a positive future for the use of technology, it important that ethics becomes a central element of computer science education. To this end, the Ethics4EU project has developed curricula on a wide range of topics including privacy and agency of personal information, digital literacy, data governance and accountability, surveillance applications, algorithmic decision and automating human intelligence for robotics and autonomous vehicles. Crucially the content examines computing ethics, not only in terms of hardware and software, but how systems, people, organisations and society interact with technology.In this paper, we present our interdisciplinary approach to developing educational content for AI Ethics. This includes accessible teaching materials, in-class activities, sample assessments, practical guidelines and instructor guides. We discuss findings of an evaluation of the developed content with undergraduate computer science students.

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1 INTRODUCTION

1.1 Background

Computers and technological applications are now central to many aspects of life and society, from industry and commerce, government, research, education, medicine, communication to entertainment systems. These technologies have wide ranging impacts on society, and despite the many ways new technologies have improved life, they cannot be regarded as unambiguously beneficial or even value-neutral.There is a sense that some technology development and innovation is happening at a more rapid pace than the relevant ethical and moral debates.

The history of computing ethics (or computer ethics) goes hand-in-hand with the history of computers themselves; since the early days of the development of digital computers, pioneering computer scientists, such as Turing, Wiener and Weizenbaum, spoke of the ethical challenges inherent in computer technology [1], but it was not until 1985 that computing ethics began to emerge as a separate field. This was the year that two seminal publications were produced, Deborah Johnson's book Computer Ethics [2] and James Moor's paper, "What Is Computer Ethics?" [3]. Deborah Johnson's *Computer Ethics,* was the first major book to concentrate on the ethical obligations of computer professionals, and thoughtfully identifies those ethical

issues that are unique to computers, as opposed to business ethics or legal ethics. In James Moor's paper [3], he defined computer ethics as "the analysis of the nature and social impact of computer technology and the corresponding formulation and justification of policies for the ethical use of such technology", and argues that computer technology makes it possible for people to do a vast number of things that it was not possible to do before and since no one could do them before, the question may never have arisen as to whether one ought to do them.
In the 1990s, and the concept of "value-sensitive computer design" emerged, based on the insight that potential computing ethics problems can be avoided, while new technology is under development, by anticipating possible harm to human values and designing new technology from the very beginning in ways that prevent such harm [4]. Others including Donald Gotterbarn [5], theorised that computing ethics should be seen as a professional code of conduct devoted to the development and advancement of standards of good practice for computing professionals. This resulted in the development of a number of codes of ethics and codes of conduct for computing professionals, for example the ACM "Guidelines for Professional Conduct".
In 1996 the "Górniak Hypothesis" predicted that a global ethic theory would emerge over time because of the global nature of the internet. Developments since then appear to be confirming Górniak's hypothesis and have resulted in the metaphysical information ethics theory of Luciano Floridi [6]. These new theories make explicit the social and global change created by new technologies and call for an intercultural debate on computing ethics in order to critically discuss their impact on society.

1.2 Ethics4EU

The Ethics4EU project [7], is exploring issues around the teaching of ethics in computer science curricula. To understand gaps in the prorvision of ethics education and how to address then, the project undertook a pan-European survey of attitudes of computer science faculty towards teaching computing ethics [8]. The survey was completed by faculty at 61 universities across 23 different European countries. This found that 36% of respondents (or 22 universities) do not teach any computer ethics, citing either a lack of available time or a lack of expertise as being the key reasons as to why they don't teach this topic. When institutions do teach Computer Ethics, they tend to devote a relatively small number of hours to teaching Computer Ethics on their Computer Science or related programmes - 67% of institutions surveyed teach 10 hours or less per semester. Our survey also revealed that computer ethics is often taught as a standalone subject. This is in spite of evidence that infusing computer ethics in Computer Science curricula gives students a better understanding of the ethical impacts and possible harmful effects of the technologies they implement.

Research has consistently shown that ethics is an important missing element in computer science education unlike all other science disciplines [9]. Furthermore our survey results show that there is a lack of staff availability and expertise to teaching computing ethics [8]. Thus one of the key objectives of this project is to develop a 'train the trainer' range of teaching content and instructor guides to facilitate computer science faculty in the instruction of computing ethics. In this paper we present and evaluate educational content that was developed as part of the project, specifically lessons that focus on ethics related to computer programming errors.

The content is designed to serve as a way to improve computer science students' ability at consequence scanning – a way to consider the potential consequences of new software on people, communities and the planet [10].

2 METHODOLOGY

2.1 Case Studies

In this work, we describe the development and evaluation of educational content that addressed AI (Artifical Intelligence) ethics. A case study method was chosen as these are designed to explore real-world phenomena and they focus on interpreting events and exploring the impact of the case study on the broader society, including ethical issues [11]. Four case studies were carefully selected and developed by interdisciplinary teams of Computer Scientists and Ethicists, which focused on a number of programming-related ethical scenarios. The four case studies are briefly described below. The full case studies plus the in-class activities used to deliver the case studies are available at (Ethics4EU website [7]):

2.1.1 Irish State Examinations 2020

As in many countries, the Covid-19 pandemic had a profound effect on Irish state examinations in 2020. Due to a national stay-at-home rule, state examinations were cancelled and replaced with an algorithmic estimated-grading system. A student's grade in each subject was estimated based on their expected performance combined with their School's statistical profile of achievement. A national standardisation process was applied to ensure a consistent standard in the estimated-grade process across the country. A subsequent review of the standardization process revleaed that the algorithm produced a disproportionately negative outcome for high performing students from historically low performing schools. As soon as the errors were detected, the affected students were identified and corrections made. However, delays in making these corrections meant that some students had not received correct offers for university places and had to wait to commence their third-level study in the following academic year.

2.1.2 Search Engine Bias

The Google auto-complete algorithm looks for common queries that match what a user starts to enter into the search box but also considers the lauguage of the query, the location a query is coming from, trending interest in a query and the user's past searches. Google's rationale for offering auto-completion is to provide a more personalised search experience, however there are many recorded instances where autocompletion makes poor or even problematic suggestions that have prioritized sites with extremist biases.

2.1.3 Judicial Sentencing Software

Some courts of law in the United States of America are employing commercial software systems to assist the judiciary in sentencing criminal defendants. A ProPublica analysis of one of these sentencing systems, the COMPASS system found evidence of racial bias when making a sentencing recommendation [12]. The team found that "blacks are almost twice as likely as whites to be labeled a higher risk but not actually re-offend," whereas COMPAS "makes the opposite mistake among whites: They are much more likely than blacks to be labeled lower-risk but go on to commit other crimes ». They also found that only 20 percent of people predicted to commit violent crimes actually went on to do so.

2.1.4 Autonomous Vehicles

In recent years, the automobile industry has seen some car manufacturers incorporating self-driving as an available feature. This feature enables the car to autonomously navigate between two geographical points without any, or minimal, intervention by the driver. The car uses an array of sensors to capture data in its environment, which is input to software controlling the car's mobility

and navigation. The software developed to enable autonomous self-driving must be capable of responding to the threat of a potential or imminent accident. When implementing these algorithms, programmers need to be cognisant of parameters that might include legal, moral, cultural, ethical and geographical factors.

2.2 Evaluating the Case Studies

We wanted to understand if computer ethics case studies highlight the importance of ethics for computer professionals and whether delivering the computer ethics case studies in a constructivistic manner help students see the case from multiple perspectives. One case study per week was delivered (over 4 weeks) as part of a first-year programming module between the 15th of April 2021 and the 30th of April 2021. The group composed of 175 first year computer science students at Technological University of Dublin, Ireland. The content was delivered using a virtual classroom for the main lessons, with breakout rooms for the students to discuss the ethical issues from each session in smaller groups, and Padlet (https://padlet.com/) was used as an idea sharing space where participants could highlight their key take-aways from each lesson. The lecturers recorded their reflections about the classes on a weekly basis in diaries. After the lessons were completed, the students were invited to participate in a survey to collect their feedback on the process.

3 RESULTS

A student survey was deployed using Microsoft Forms between the 30th of April 2021 and 3rd May 2021, and a total 25 students responded to the survey giving a response rate of 14.3%. The students were given the following key instructions: (i) the survey is voluntary, (ii) all submissions do not record the students' names, and (iii) the results will be published as part of the broader discussion on these issues. The survey had seven questions (two closed-ended and five open-ended) and was developed based on a combination of the Learning Object Review Instrument (LORI) [13] and some examplars from Oppenheim's book on questionnaire design [14].

The findings were very instructive, including the fact that the majority of students (23 out of 25) rated the content as "Very Interesting". Specifically the students commented that it was interesting to explore how much of an impact the systems that they develop could have on other people's lives (as one commented "*how the programs … can potentially change someone's life for worse or better*"), particularly the case studies highlighted the potential dangers when computer programs are written in a rush or don't observe good programming practices.

The students also noted how the structure of these lessons differed from their typical classes, as they had more time to interact with their classmates, and hear different perspectives on a particular topic (one student commented that "*the case studies were different from regular lectures and felt like a fun TED talk, with additional audience engagement*"). This theme was further expanded upon in answers to different questions, including for example "*The group discussion helped to show different perspectives from my classmates.*" and "*discussion about* [the cases] *and sharing of ideas helped me see things newly*". Interestingly, many students changed their minds on these topics based on these interactions, for example, "*I used to think technology was the answer to everything but after talking to others about* [it], *that really changed my perspective on it*". Also many commented on their expanded appreciation of ethics in programming, for example, "*I hadn't considered that there were ethics to think about in programming but having talked to people I realized now ethics can be applied everywhere*".

Another striking theme that emerged was how the case studies prompted the students to consider other people in the design of algorithms, for example, one noted that "*We all have different views on what ethics is so it is important that people from different backgrounds are always included when developing an algorithm*". Specific groups were mentioned as being especially important in this expanded perspectives, such as "*minorities and people with disabilities*" as well as "*the perspectives of the most vulnerable*".

The lecturers' diaries provided additional insight into the case study approach, they commented that the topics chosen were successful because they were highly relevant to the students and very tangible examples of the challenges inherent in software development. They also commented on the fact that it is difficult to find good case studies that successfully balances the algorithmic aspects of the case with the ethical aspects, for example, in terms of the first case study on the Irish State Examinations, all of the participants were very much engaged in how a small algorithmic error can impact thousands of people, but they felt there wasn't significant ethical nuance to that particular case (when compared to the others). They felt the cases that involved more sophisticated Artificial Intelligence (the Judicial Sentencing Software and the Autonomous Vehicles Cases), were the ones that best balanced the ethical and technological considerations, and, in particular, the Autonomous Vehicles case provoked the most debate and controversy. The lecturers enjoyed this constructivistic approach to teaching, and where they gave the students time to work with each other, and truly reflect on novel and interesting topics.

4 ACKNOWLEDGMENTS

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Drawing from SEFI ethics knowledge to support ecological ethics in technological education.

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ABSTRACT

We are leading a project called Ethico within the European University of Technology (EUt). Ethico aims to design and promote the uptake of innovative, ecological ethics for technological education.

This practice paper briefly summarizes the aims and structure of the Ethico project, and then focuses on the work completed as part of the teacher training module developed in Cluj, 7-9th March, 2023. This workshop drew its conceptual framework from the short abstracts currently available for the Engineering Ethics Education Handbook. The structure developed was then implemented in a student facing workshop in Troyes between the 10-14th July 2023. The handbook is under development by SEFI's Ethics special interest group, who shared the content with us (the second author of this paper is part of both projects). We drew particularly from Theme 3 of the handbook, which covers Teaching Methods for Engineering Ethics Education (EEE), for the Intensive Study Periods in Cluj and Troyes.

Drawing from these EEE abstracts, we designed and tested a teacher training course, with the express aim of achieving flexibility for appropriate application in diverse cultural and administrative university settings. This is because the EUt is comprised of eight universities in eight separate European countries. We explored

how we could apply the literature review chapter of theme 3 (on education methods) and of the *EEE Handbook*, as well as the dialogical/reflective chapter, and some of the specific pedagogical methods for building student awareness, understanding and analytical decision making in ethics. Our work in Cluj focused on three of the Student-Centred Learning approaches presented in the Handbook— case studies, challenge- and problem-based learning, and Virtuous Practice Design—with very promising results.

The paper examines the ethical model engaged with and the teaching models developed at the EUt event in Cluj and Troyes using the *EEE Handbook*. It outlines our proposed module for eco-ethics in technological education, highlighting the key tensions for implementation in cross-cultural and interdisciplinary contexts and incorporates preliminary feedback from student participants.

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1 INTRODUCTION

Engineering students need to understand ethics and ecology, including environmental and social justice models, in order to practice effectively in today's rapidly changing world. Weighty challenges have resulted from the Anthropocene era—where human activity has become the dominant influence on both the environment and the climate—and we believe it is imperative to re-conceptualize and re-prioritize how ecological ethics feature in higher education.

To accomplish this, we argue that firstly we need to establish transdisciplinary educational methods to establish multi-perspectival and value-based ethics. Secondly, we need to reconceptualize both ecology and technology as well as the discourses and associations that surround them (Steigler, 1998). Thirdly, we need to bring about a shift in the ethical models we use to regulate our development and implementation of technologies at individual, societal and global scales (Guatarri, 2000).

We further argue that, through the teaching of eco-ethics, educators can provide learners with the tools needed to guide their decision-making processes toward ecologically sound and sustainable outcomes. Helping students locate and frame eco-ethical problems in contemporary scenarios forms an essential step in effectively addressing contemporary challenges. But how can this be accomplished, and how can we move the field of engineering, as it is envisioned and practiced within and beyond technological universities, toward embracing and enacting the values of eco-ethics as a praxis of decision making?

The authors of this paper are providing leadership for a project called Ethico that is part of the European University of Technology (EUt), an alliance of eight (soon the be nine) universities across Europe working together to align our curricula and pedagogical methods in ways that provide greater transparency, flexibility and responsiveness to the needs of European and global societies.[1] Ethico is an Erasmus+ funded project that is part of the European Culture and Technology Lab (ECT Lab+) created by and for the EUt. Ethico aims to design and promote the uptake of innovative education methods that integrate ethics and ecology and are transferable to the many varied disciplines provided across the EUt, from arts and humanities to engineering and environmental sciences. Ethics, in our context, is understood as a form of praxis, led by virtues that guide accumulative decision making to a collective goal at individual, societal and planetary scales (Guattari, 28). To develop this module, we drew from the *EEE Handbook.*

[1] The participating universities are the following: Cyprus University of Technology, Darmstadt University of Applied Sciences, Riga Technical University, Technological University Dublin, Technical University of Sofia, Universidad Politécnica de Cartagena, Université de technologie de Troyes and the Universitatea Tehnică din Cluj-Napoca.

2 HANDBOOK

The SEFI Ethics SIG took the lead on compiling a comprehensive, state-of-the-art overview of the existing research in Engineering Ethics Education (EEE). The *Engineering Ethics Education Handbook* under development provides teaching, research, philosophy, and administration perspectives, to deliver a useful resource for established academics and new researchers who want to enter this field. Thus far, 115 researchers from various parts of the world have been involved in the work. Engineering is currently being taught at different types of educational institutions worldwide, ranging from universities to technical institutes, including the emerging Technical Universities in Europe. The knowledge compiled and synthesized can enhance the teaching methods at these institutions. The knowledge of EEE will be presented in six sections each representing a central research area of EEE:

1. **Foundations of Engineering Ethics Education**
2. **Interdisciplinary contributions of Engineering Ethics Education**
3. **Teaching methods for Engineering Ethics Education**
4. **Accreditation of Engineering Ethics Education**
5. **Ethical issues in different engineering disciplines**
6. **Assessment of Engineering Ethics Education**

The section used by Ethico for its teacher training module, is ‘teaching methods’. The theme comprises seven chapters, all of which are of potential use to Ethico and the EUt. Ethico took five of these sections as the structure for the teacher training module; a module designed to train teachers to incorporate ecological ethics into pre-existing curricula. Five of the abstracts form the thematic core for five micro-credentialised workshops.

The third section of the handbook aims to identify established and emerging methods of teaching engineering ethics. Current research indicates a lack of coherence and confusion among educators about the most effective approach to prepare socially responsible engineers, and limited empirical evidence to guide instruction. The first chapter of the section will provide a “Literature Review Mapping the Use of Teaching Methods in Engineering Ethics Education” (Polmear, M., Borsen, T., Love, H., & Hedayati, A., *pending*). The authors explained that they will identify the established and emerging teaching methods used in engineering ethics and provide a broad view of how it is taught. The chapter will describe the patterns and trends regarding teaching methods, and will emphasize the importance of aligning learning objectives, teaching methods, and assessment strategies to improve instruction effectiveness. The abstract of this section has been used to structure the first module for the overall EUt Teacher Training course alongside the literature review generated by Ethico.

The second chapter will discuss “Teaching Ethics Using Case Studies” (Herzog, C., Jorhi, A., Gordon, D. T., & Roach, K. *pending*). The authors have proposed to evaluate the use of case studies in engineering ethics education, providing arguments for and against their adoption and discussing their potential contribution to the classroom. They will present ways to integrate case studies into teaching, including real-world case studies and role-play scenarios, and showcase various repositories of engineering ethics case studies. As case studies represent a viable and well-tested method for teaching ethics to students of engineering and technology, this content will be of great interest and use to EUt stakeholders and will be highly referenced in the design and delivery of EUt's Teacher Training course. Inspired by this, one hoped outcome of Ethico is an online database of approved case-studies. The generation of a case-study is also one potential assessment technique for the teacher training course, permitting continual generation of new, free-to-access case-studies.

The handbook theme's third chapter will discuss "Challenge-based and Problem-based Learning in Engineering Ethics Education" (Bombaerts, G., et al). The authors intend to address an existing gap in research on challenge-based and project-based learning in engineering ethics education. These methods have become increasingly visible and the EUt stakeholders attending the Intensive Study Period (ISP) in Cluj-Napoca saw great value in applying the abstract and forthcoming content of this chapter for the Teacher Training course.

The fourth chapter, will focus on "Ethics in Service Learning and Humanitarian Engineering" (Daniel, S., Yeaman, A., Navarro Forero, C. A., & Oakes, W. *pending*), *Ethics in Service Learning and Humanitarian Engineering*.
It will discuss the future of engineering ethics education in the context of societal needs and global responsibility. It will examine the ethical challenges posed by emerging technologies and the implications for engineering ethics education.

The handbook theme's fifth chapter will discuss "VSD and Beyond - Value Sensitive Design and Design-Based Learning in Engineering Ethics Education" (Gammon, A., Zolyomi, & Van de Poel, I., *pending*). This chapter will present VSD as a leading approach for introducing ethical and value considerations to engineering and design students. The chapter will introduce VSD, including its key ideas and commitments, explaining how it has been taken up in design and engineering education. This chapter's abstract was a focus of the discussion in Cluj around the move towards holding virtue ethics at the core of technological education as opposed to applied ethics (Reijers, W., & Gordijn, B., 2019).

The sixth chapter will discuss "Arts-Based Methods in Engineering Ethics Education" (Hitt, S. J., Gillette, D., Shumaker, L., Lefton, T., 14) and relates to the transdisciplinary goals of the Ethico project. The chapter's authors seek to explore the value of incorporating arts-based teaching in engineering education, particularly in the context of ethics education. The authors will examine how arts-based methods have been defined, described, and assessed in educational contexts and how they might help achieve ethical education outcomes that other methods do not.

The final chapter was of great relevance to the ISP in Cluj, although participants lacked adequate time to discuss the ideas in detail. That forthcoming chapter will discuss "Reflective and Dialogical Approaches in Engineering Ethics Education" (Martin, L., Jalali, Y, Morrision, A., & Voinea, C., *pending*). In it, the role of reflection as a valuable learning experience in the ethics classroom will be explored, as well as dialogical techniques that can foster or provoke reflection among engineering and STEM students in existing curricula. The authors have proposed to open the chapter by describing ethical reflection as a core competency, to enable both “moral deliberation and responsible action” among future practitioners. One way in which this has been developed for Ethico is in the use of a student-completed glossary, trialed in at the ISP held in the Technological University of Troyes (UTT) (see Fig. 3).

The participants in Cluj were enthusiastic about using the handbook and eager to see it published. The chapters were used to structure the following iteration of the ISP at UTT between the 10-14th of July and form the core of teacher training and student facing modules of Ethico. Many expressed sincere interest in inviting the authors and editors of the handbook to help guide the faculty or their own campuses in implementing the approaches covered in the handbook. In this regard, the handbook has facilitated future transdisciplinary collaboration between different European educational institutions.

3 ETHICO

The following sections outline the aims and structure of the Ethico project, and then focus on the work completed as part of the teacher training module developed in Cluj, from the 7-9th of March, and implemented in the last ISP ran from 10-14th July, 2023 at UTT. Both iterations constructed their conceptual framework from the short abstracts currently available in the *Engineering Ethics Education Handbook*, which is under development by SEFI’s Ethics special interest group (SIG). The six editors of the Handbook, all members of the Ethics SIG, agreed to sharing the abstracts with us and have been enthusiastic about seeing their author’s content being applied in practice.

We drew from the short abstracts that had been prepared for the handbook’s publishing company when developing the schematic design of a teaching training course with flexibility to apply in the diverse cultural and administrative conditions of the partners in our EUt alliance. In Cluj, we explored how we could apply the literature review and dialogical/reflective chapters of the EEE Handbook, as well as three of the SLC pedagogical approaches featured in the handbook: case studies, challenge- and problem-based learning, and Value Sensitive Design and beyond, to include Virtues Practice Design.

The overall teacher training course for EUt involves five components with each one attributed 1ECT credit. The first comprises an introductory session to define essential terms and describe the framework we’ve used. This grounding framework is followed by three pedagogical application sessions where teachers learn to use various student-centred learning (SCL) approaches to delivering content related to eco-ethics and to explore ways of applying the techniques within their own EUt disciplines. The teacher training course culminates with a dialogical and reflective component to help teachers understand the role of reflection and how to prompt students to become reflective learners and practitioners (see Fig. 1). All five of the elements of the course listed above are covered in chapters of theme 3 of the *EEE Handbook* (Børsen, T., et all, *pending*).

Day	Activity
1	- Workshop to establish communal understanding of ecology. - Lecture on Ethics models, techne and ecology. - Introduction to Ethics Canvas. - Introduction to glossaries as tool.
2	- Case Study methods.
3	- Challenge- and Problem-based learning methods.
4	- Virtues Practice Design methods.
5	- Dialogical/Self-Reflective methods. - Summary discussion of Implementation. - Comparison of glossaries. - Summary discussion of *Ethics Canvas*.

Figure 1, *Outline of the Ethico Teacher Training Module*

We believe that, once published, the *EEE Handbook* can serve as a resource for EUt educators, as well as people running or attending teacher training sessions across the EUt. Our activities can also serve as inspiration, providing a precedent from others outside the EUt to emulate.

This model was then adapted for the student-facing component at the UTT. Twenty-seven student participants ranging from Masters to PhD level were brought together at UTT and given the following courses that had been developed from the *EEE Handbook* and its first use in Cluj. First, they engaged in a series of lectures and workshops, discussing the broader themes, discourses and literature of ecological-ethics. On day two, they were introduced to the problematisation of case-studies and problem-based learning through real world examples. They were then tasked to use VSD in a speculative workshop to imagine the future of the EUt Sustainability Lab. Throughout the four day workshop, each student was also tasked to maintain a glossary that had space for the word, definition and a personalised example (see Fig. 3). These glossaries were compared, alongside the different outcomes in a self-reflexive and dialogical session at the end of the ISP. Furthermore, students completed an anonymous survey before and after completing the workshop via Mentimeter. The following pages will summarise the activity taken place in Cluj and Troyes, its use of the *EEE Handbook,* and the results of these days.

4 ETHCIO: DEVELOPING AND TESTING THE TEACHER TRAINING COMPONENT

On the first day of the Ethico module in both Cluj and UTT, participants from the eight different EUt universities were asked to engage in a learning activity designed by UTT to develop a shared understanding of ‘ecology’. In this activity, piloted in 2021 online, participants develop tree diagrams that use the matrices created by UTT to demonstrate the permeability of classic ontological categories (see Fig. 2). Participants are first asked to begin mapping the “roots” of the trees, making a differentiation between different human (h), technical systems (ts) and nature (n). Participants are then asked to map the different h, ts and n actors, and demonstrate, through the prepared matrices, the different ways in which h, ts and n systems interact. This exercise aims to demonstrate to participants the co-formation that exists between technical objects and biological systems, what is termed, a biosocial-technological matrices (Steigler, 1998).

The diagrams developed are then used to understand a real-world example related to climate change, and participants were tasked with exploring the different roles h, ts and n actors play within the case study using the Ethics Canvas (developed by ADAPT). Participants were asked to rank the severity of the impact of the situation presented in the case study, from the perspective of each identified actor. Through this activity, participants were guided to an understanding of the inability for a cause-effect to be drawn that excludes one actor from another. This cultivates a system(s) thinking approach within participants, at varying scales, from the personal, to the societal, to the global.

The H-tS-N matrix has been shown to be a tool for case study analysis in around forty minutes. The session ends with a discussion of values and ethics that establish critical viewpoints on the H-tS-N model and facilitators are expected to guide this conversation from definitions of terms, towards questions of ethics. Participants were also asked to take notes, reflecting on their own thinking, which was used in conjunction with the dialogical end unit. This was piloted in Troyes very successfully, with students commenting on the way it aided in trandsiciplinary conversation.

Lecture on Ethics, Techne and Ecology

The second half of the first day covers Ethics, Techne, and Ecology, with a lecture that argues for a shift in the way ethics is taught in engineering education. The lecture highlights the need to move away from the dominant form of ethics taught, which is applied ethics, and towards virtue ethics, which is more adaptable and dynamic. A need that was made clear in the primary demonstration of the results of Ethico at the 2022 CREATE research symposium (Benedicic, Ursa et all, 2022). The lecture emphasizes an expanded view of technology that includes not just mechanical objects such as cars or computers but is inclusive of tools that connect humans with the world, and allow them to ‘become’ in it, such as art, language, and communication. The lecture develops an ecological ethics for "techne" education, which is inherently transdisciplinary.

The goal of developing ecological ethics for technological education is to give learners the tools to make accumulating decisions that benefits all actors, recognizing the different roles of all components in the formation of the whole. Developing ecological ethics involves expanding the categories of human, natural, and technology and establishing a praxis of care in the relationality between posthuman beings, techne, and an ecology of pluralistic actors (Bellacasa, 2022). Ethico proposes a framework based on a set of virtues to guide decision-making processes that are both varied and coherent. This approach aligns with Paul Ricœur’s notion of little ethics, where the sum of micro-decisions forms an ethical whole while retaining epistemological diversity and specificity in actions, which has been used in other scientific practices including Marie-Josée Potvin’s bioethicist practice (Potvin, 2010). Although this model may be critiqued for a lack of criticality towards virtue ethics (Moldoon, 1998).

This lecture, delivered by Prof. Noel Fitzpatrick was highly successful in both Cluj and Troyes and has been recorded as a learning resource at UTT. Learners and educators alike have requested that it be made available online for integration into their existing curricula – and following the anonymous survey, all participants felt ‘more prepared to make ethical decisions in their practice’ following this content.

Case Studies and Problem-Based Learning
Following the guidance of the *EEE Handbook,* in Cluj and Troyes, with educators and learners respectively, we engaged in a series of real-world case-studies during the second day of the workshop. These included the case study of a fire in a pig farm developed by Pauline Picott, Ester Toribio Roura and Jye O’Sullivan and one focussed on the Colectiv nightclub fire in Cluj-Napoca (2015) developed by Silivan Moldovan. For the first case study, the participants were asked to role-play different members of a jury to develop perspective from multiple stakeholders. Furthermore, this use of role-play engaged with arts-based methods for transdisciplinary education. In the second, the participants were asked to analyse the case study according to its problematics using the *Ethics Canvas,* a tool developed by the ADAPT centre.

Through this variety of approaches, educators and learners alike were introduced not only to problem-solving, but to locating ethical problems from multiple (and more-than-human) perspectives. This shift away from problem-solving represented a significant step forward in the implementation of ecological-ethics.

Self-Reflexive and Dialogical Session
In Cluj, educators were given the opportunity to develop ideas around how to cultivate ethical self-reflection in engineering education. In Troyes, we addressed this component by asking students to complete glossaries throughout the week (see Fig. 3). Furthermore, they were asked to complete a Mentimeter anonymous survey before and after the workshops (see Fig. 4). The glossaries and mentimeter results, along with the complete Ethics Canvas’ from the prior module then formed the basis of an open ended discussion on self-reflection and ethics as praxis. Through comparing a contrasting different terminology and embodied understandings, we were able to firstly, ensure that the course had been well delivered through conversation around the key learning outcomes and discourses. Secondly, however, we were able to demonstrate the benefit of continual self-reflection inside and outside of the classroom, and therefore also demonstrate the benefit of viewing ethics as a self-reflective praxis as opposed to an applied code.

Students were highly receptive to this dialogical component and asked for an extention to the time of this module. Reviewing the Mentimeter results, nearly 70% of the students found the glossary a useful tool throughout the module and 100% of students stated they ‘felt more informed on the question of ecological ethics’. Perhaps most significantly, all of the participating students stated that they felt more prepared to make ethical decisions in their practice after this training module. This is coherent with the individual interviews conducted throughout the module, which are awaiting anlysis.

5 RESULTS AND CONCLUSIONS

The authors have found that the use of the handbook and the methodologies it outlines, greatly enabled the teaching of Ethico's proposed ecological ethics framework and significantly reduced potential frictions in its uptake across disciplines. Drawing on the specialist knowledge of the handbook, the Ethico module has been enriched in its capacity to bring critical contemporary sociocultural and philosophical thinking around ecological ethics to a wide variety of disciplinary practices through a robust, informed and pedagogically viable set of methods, derived from the *EEE Handbook.*

These methods have successfully provided a framework that can be adapted for disciplinary, cultural and institutional differences, whilst still maintaining enough coherency to be validated for teaching at the EUt level. By giving educators this set of tools, it is hoped that they will be able to incorporate the eco-ethics framework developed by Ethico into pre-existing curricula, as a form of embedded learning through micro-credentials, a proposal that has been well received across the eight university partners.

Having completed an online trial of the H-tS-N matrix in 2021, the lecture component each year from 2020-23 and having collectively formulated the structure of the teacher training module using the *EEE Handbook,* our trials in both Cluj and Troyes were highly successful. All interviewed students both reported that there was a need for more complex ethical models, beyond applied ethics, to be introduced into technological education, and reported that they found the ISP very useful in establishing a groundwork for this. According to the mentimeter conducted at the end of the ISP, students on average rated the ISP as 4.4 out of 5 in usefulness. Furthermore, 88% of students who participated in the final mentimeter stated that the discussed 'ethical decision-making models' were applicable in their practice (see Fig. 4), although only 63% of students felt that 'the incorporation of eco-ethical models into the curricula at your institution would be well received'.

Coherent with the literature review of both the *EEE Handbook* and the Ethico project, there is a clear need and want for the incorporation of innovative ecological ethics models in technological eduction, however an anxiety surrounding the implementation and reception of these models in existing faculties. One notable problem evidencied in the mentimeter, was that there was no significant change in students willingness to use ethical models over 'the specific situation'. This demonstrates the need to instruct more clearly the range of ethics models as different tools to help in distinct situations. We will identify different ways this can be achieved after the qualitative analysis of the glossaries and interviews conducted in Troyes. Initially, however, the glossaries demonstrate a high level of embodied learning, and self-reflection (see Fig. 3).

The Ethico team are now in discussion with the EUt Sustainability Lab and are working on credentialising the module for use across the EUt. We have identified this as an outstanding opportunitiy to continue collaboration with the authors of the *EEE Handbook* and to establish transdisciplinary eco-ethics in technological education at a European wide scale.

5.1 Figures

Figure 1. *Proposed schedule of activity for Ethico module.*

Day	Activity
1	- Workshop to establish communal understanding of ecology. - Lecture on Ethics models, techne and ecology. - Introduction to Ethics Canvas. - Introduction to glossaries as tool.
2	- Case Study methods.
3	- Challenge- and Problem-based learning methods.
4	- Virtues Practice Design methods.
5	- Dialogical/Self-Reflective methods. - Summary discussion of Implementation. - Summary discussion of *Ethics Canvas*. - Comparison of glossaries.

Figure 2, *H-tS-N matrix,* Developed by Nadege Troissier and Santiago Perez, 2021.

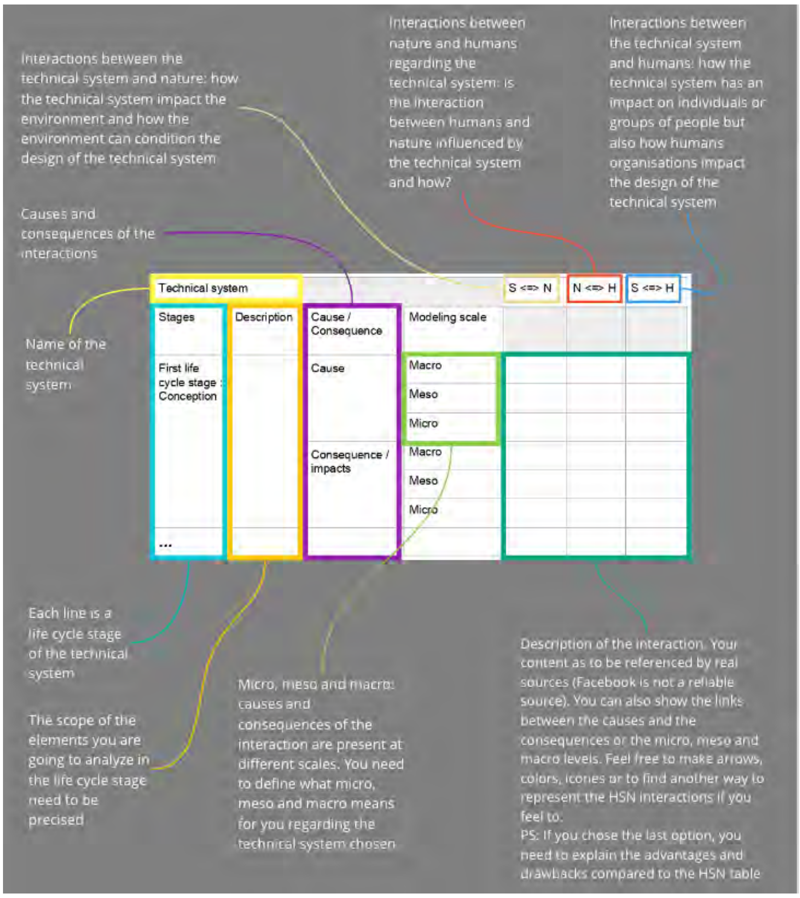

Figure 3, Student Glossary Example, used in ISP3 at UTT, 10-14 July, 2023

EUROPEAN UNIVERSITY OF TECHNOLOGY

Glossary for Ethico Intensive Study Program: Troyes

Word	Meaning	Example
Friction	**Español:** se refiere a los conflictos éticos o morales que surgen cuando se enfrentan diferentes valores, principios o intereses en un determinado campo, como la ingeniería. Estos conflictos éticos pueden generar tensiones y desafíos al tomar decisiones éticas. **Inglés:** refers to the ethical or moral conflicts that arise when different values, principles or interests are confronted in a given field, such as engineering. These ethical conflicts can generate tensions and challenges when making ethical decisions.	**Español:** En la ingeniería, cuando un ingeniero se enfrenta a la disyuntiva de seguir los estándares de seguridad y protección ambiental en un proyecto, a pesar de los posibles costos financieros adicionales que ello pueda conllevar. La fricción ética se presenta cuando los valores de responsabilidad y sostenibilidad chocan con las consideraciones económicas y de eficiencia. **Inglés:** engineering, when an engineer is faced with the dilemma of following safety and environmental protection standards on a project, despite the possible additional financial costs that this may entail. Ethical friction arises when the values of responsibility and sustainability clash with economic and efficiency considerations.
Ecology	**Español:** Es una ciencia que estudia la relación/conexión que existe entre los seres vivos y el ambiente que nos rodea, además de cómo influye en la biodiversidad, nuestra conducta y posibles interacciones entre las diferentes especies que convivimos, así como las modificaciones que ocasionamos en el medio ambiente. Ejemplo: Los ecologistas estudian cómo los cambios en el ecosistema afectan a las especies que lo habitan.	**Español:** los ecologistas estudian cómo los cambios en el ecosistema afectan a las especies que lo habitan. **Inglés:** ecologists study how changes in the ecosystem affect the species that inhabit it.

Figure 4., Table of Mentimeter Results taken on the first and third day of ISP3 in Troyes

Pre-ISP		**Post-ISP**	
How much experience do you have in Ethics? (1-5)	1.8	How useful was participating for you?	4.4
Are you familiar with different ethical models	5 No 17 Yes	Do you feel more prepared to make Ethical decisions in your practice after training	14 yes 0 no 2 no answer
		To what extent did you find the use of a	6.9

		glossary helpful as a tool (1-5)	
When evaluation ethical behaviours do you tend to be driven by:	1 Ethical Models 4 Personal Experience 4 Intuition 15 The specific situation	When evaluating ethical behaviour, do you tend to be guided by?	0 Ethical models 4 personal experience 2 intuition 12 the specific situation
For me, the personal judgment of ethical behaviour in the situation is more important than the consensus reached between the participants when deciding	18 yes 9 no	For me, the personal judgment of ethical behaviour in the situation is more important than the consensus reached between the participants when deciding	7 yes 12 no
How important is it for me to think about the consequences of unethical behavior in the case studies? (1-5)	4	How important is it for me to think about the consequences of unethical behavior in the case studies? (1-5)	4
Is nature separate from culture?	4 yes 22 no	Is nature separate from culture?	5 yes 12 no
Are values important to making ethical decisions?	26	Do you think the incorporation of eco-ethical models into the curricula at your institution would be well received?	12 yes 7 no
Is there a need for ecological ethics in your discipline?	22 yes 2 no	Do you feel more informed on the question of ecological ethics	18 yes 0 no

When do we make ethical decisions?	0 When required 5 When acting in a way that affects others 18 Constantly	When do we make ethical decisions?	0 When Required 3 when acting in a way that affects others 14 Constantly
		Do you think the discussed ethical decision-making models are applicable in your practice?	16 yes 2 no

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Unlocking complex Vector Calculus concepts for engineering students using GeoGebra

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Keywords: *GeoGebra, Vector Calculus, engineering students, visualisation, conceptual understanding, double integrals*

ABSTRACT
There is an increasing drive to exploit the power of technology to improve students mathematical conceptual understanding. This work is motivated by the authors research presented at the SEFI 2022 conference which reported on students experienced difficulties with the double integral, a concept central to vector calculus. Some of the difficulties included visualising and sketching three dimensional surfaces and regions of integration and changing coordinate systems from rectangular to polar. Vector calculus is a crucial subject for engineering students, but its abstract concepts can be challenging to grasp. This curriculum proposal is a response to improve visualisation and conceptual understanding and is part of a larger project to develop an innovative, engaging and effective way for undergraduate engineering students at the University of Cape Town to learn vector calculus concepts supported by GeoGebra. The choice was made in favour of the easy to use, freely downloadable mathematical software, GeoGebra which presents a creative, visual and integrative way to experience and understand mathematical concepts.

Informing this curriculum development initiative is Vygotsky's social constructivist perspectives with an emphasis on inclusivity, diversity and participant interactions. In this paper we discuss the above theoretical underpinnings with case studies on how to teach the double integral concept in GeoGebra for conceptual understanding. Additionally the benefits of using GeoGebra including its ability to engage students, promote critical thinking, and increase motivation will be discussed. This research will be of interest to those intending to use GeoGebra to improve the teaching and learning of vector calculus concepts.

1. INTRODUCTION

Vector calculus is a fundamental subject for engineering students, but its abstract concepts can be challenging to grasp. One of the key concepts that students often struggle with is the double integral, which is central to vector calculus. In a previous study presented at the SEFI 2022 conference, we reported on the difficulties that students experienced with this concept, including visualising and sketching three-dimensional surfaces and regions of integration and changing coordinate systems from rectangular to polar. Students perceive the integration of functions of one or more variables as one of the most challenging calculus topics (Kiat, 2005; Mahir, 2009; Maharaj, 2014; Pino-Fan et al., 2018), because typically it is not enough to apply procedures in calculating integrals. This cognitive extension from single variable calculus to multivariable calculus presents challenges for students and calls on them to develop new skills and strategies to successfully navigate this transition. This makes a strong case for research needed to explore students' understanding of double integration (Larsen et al., 2017, p. 539). Our experience of teaching and tutoring various iterations of a vector calculus course confirms that our students experience difficulty understanding the concept of double integration.

To improve students' conceptual understanding of vector calculus, we propose a curriculum development initiative that uses GeoGebra, a freely downloadable mathematical software. GeoGebra provides an innovative, engaging, and effective way for undergraduate engineering students at the University of Cape Town to learn vector calculus concepts. The objective of this research is to explore the benefits of using GeoGebra to teach vector calculus concepts to undergraduate engineering students in the larger project and more specifically double integrals in this research. In the next round of research, we aim to develop case studies that demonstrate how GeoGebra can be used to teach the double integral concept in a way that promotes students' conceptual understanding.

2. LITERATURE REVIEW

In this section we highlight existing scholarship to give rationale for, illustrate significance of and situate our research. Here we consider the following: using technology for the teaching of mathematics, the challenges of teaching and learning vector calculus with a focus on double integrals, and the use of GeoGebra for teaching and learning mathematics. We include a short discussion on the theoretical framework used in this research, Vygotsky's social constructivism.

In keeping with the rapid advancement of the use of technology in the educational landscape, there is an increase in the body of research on the use of technology in teaching calculus concepts. Research shows that technology can have a significant impact on the teaching and learning of calculus concepts. Erens (2015) found that irrespective of their beliefs about the use of technology, high school teachers found that technology can be effective in teaching calculus. The often criticised approach to teaching calculus as merely computational rather than conceptual was addressed by Thompson (2013) who argues that technology enables a conceptual approach to calculus, which can help students develop connected meanings for calculus concepts. This use of technology for learning calculus may present a way to encourage students to engage with mathematics in a deeper conceptual way rather than a mere surface understanding. Supporting this notion, Cuoco (1996) suggests that technology can be used to help students develop “mathematical habits of mind and construct mathematical ideas”. Research provides evidence that technology is a valuable tool in teaching calculus concepts, but its effectiveness depends importantly on how it is used and integrated into the curriculum. Another important aspect highlighted by Raines (2011) is that incorporating technology in the classroom can enhance student learning and motivate students to become engaged in the learning process and active participants in their own learning. As instructors of calculus it is important for our students to have a good conceptual understanding and to achieve success in the course and with their future studies. Heid (1988) found that using computer programs to perform routine manipulations in an applied calculus course led to better understanding of course concepts and increased performance on a final exam.

Vector calculus is a complex subject that requires a high level of mathematical proficiency. Students have difficulties with vector calculus as it involves concepts and problems that require students to think in terms of three-dimensional space and visualize objects such as curves, surfaces, and volumes, requires students to work with functions of several variables, is typically taught at a more advanced level than single variable calculus, and requires a higher level of mathematical maturity and proficiency. Bollen (2015) found that students struggle with interpreting graphical representations of vector fields and applying vector calculus to physical situations however Lohgheswary et al (2018) suggests that teaching vector calculus using computational tools can help students visualize graphs and understand difficult concepts. Vector calculus is a challenging subject for students, and innovative teaching methods should be explored to help students understand the concepts.

Heckler (2016) found that computer-based training with elaborated feedback can be effective in improving student performance in vector calculus, especially for less prepared and low-performing students. Students learn differently and respond differently to various teaching styles. Hamzah (2022) found that the effectiveness of teaching styles can significantly affect students' achievement in vector calculus. However, Tasman (2021) cautions that the blended learning model may be less effective in improving student learning outcomes in vector calculus subjects compared to conventional learning models. What is certain is that effective teaching methods are necessary and should be explored to improve student performance especially in a challenging vector calculus course.

The focus of this research is on the double integral concept. It is well documented that students have various misconceptions when interpreting double integrals. Students often struggle to visualise and interpret three-dimensional surfaces and regions of integration, which are central to many vector calculus concepts. Additionally, changing coordinate systems from rectangular to polar can be a challenging task. Khemane et al (2022) found that students struggle with graphical representation of surfaces and regions of integration, setting up the double integral given these regions, changing the order of integration and performing the integration process.

Technology such as GeoGebra can help to improve students' understanding of calculus concepts, particularly when it comes to visualisation and interpretation. This is in agreement with Arbain and Shukor (2015), Mathevula and Uwizeyimana (2014), Niyukuri et al. (2020), Ocal (2017) and Uwurukundo et al. (2020), whose studies found that ICT, in general, could improve the way students perform in geometry, and that GeoGebra software in particular is effective in improving students geometric understanding. Importantly, Arbain and Shukor report that GeoGebra increased students' interest, motivation, enthusiasm, visualisation and performance in mathematics.

We are aware of limitations which may exist when using GeoGebra for the teaching and learning of vector calculus concepts for engineering students. These limitations may include technical limitations with regard to device access and technical expertise, learning curve for adjusting to use of new software, limited applicability as it relates to real-world engineering applications and pedagogical limitations-it may not be suitable for all types of learners. For the effective use of this software and to derive optimal educational benefit, it is important to consider these limitations when using GeoGebra to teach vector calculus concepts to engineering students. While GeoGebra can be a useful tool, it must be stressed that it should be used in conjunction with other teaching methods and techniques to ensure a comprehensive and effective learning experience.

The proposed curriculum development initiative is informed by Vygotsky's social constructivist perspective, which emphasises the importance of social interactions in the learning process. This perspective highlights the need for inclusivity and diversity in the classroom and emphasises the role of the teacher and tutor as a facilitator of learning. Additionally, the initiative is informed by constructivist learning theory, which emphasises the importance of students' active engagement in the learning process and the role of technology in supporting this engagement. Attard (2020) examines how exemplary teachers use technology to enhance pedagogical relationships with students and promote student-centred pedagogies, leading to greater student engagement with mathematics.

3. METHODOLOGY

The research question which guides this study is: *How can we use GeoGebra to improve students' visualisation and understanding of three-dimensional surfaces and regions of integration* ? This research study is situated in an engineering support programme at the University of Cape Town. The participants were engineering students enrolled for a second year, semester course in vector calculus. Ethics approval was obtained for this study and all participants willingly gave consent to participate in this research study.

The course activities and data collection reported on in this study were carried over 4 weeks. Week 1 was dedicated to lectures, tutorials, and workshops on double integrals with 130 participants. In week 2 students wrote a pre-test divided into pre-test 1 (54 participants), pre-test 2 (33 participants) according to their tutorial slots, week 3 focused on GeoGebra activities followed by an assignment (122 participants), and a post-test in week 4 (121 participants).Since participation was voluntary there is a difference in the numbers of students writing the pre-test and post-test.

3.1 Pre-test

To inform our understanding of how we could use GeoGebra to improve students' visualisation and understanding of three-dimensional surfaces and regions of integration and their (mis)conceptions of double integrals, a pre-test was given to students during their 2-hour afternoon workshop session. Since they had attended lectures on double integrals, the pre-test was designed to probe students' understanding of double integrals with a focus on their visualisation and understanding of three-dimensional surfaces and regions of integration. The first question of the pre-test identifies students' ability to sketch the region when given algebraic equations of curves which make up the region. The second question identifies students' ability to sketch 3d solids along with the projections onto coordinate planes.

3.2 The GeoGebra Intervention

As reported in our previous work (Khemane et al, 2022), sketching 2d regions and 3d solids is a prevalent challenge students face when learning double integrals. To address this, we implemented one of the suggestions from the SEFI 2022 attendees, and integrated GeoGebra in teaching double integrals. In addition to the normal lectures, students spent a week working on GeoGebra activities aimed at improving visualisation and sketching skills. Usually, students attend a 45-minute lecture followed by an hour-long tutorial aimed at reinforcing the concepts learned during lectures by working through related questions. In week 3, the tutorial sessions were substituted by GeoGebra activities. These activities were formed by a range of questions from the course handbook and student tutorials. Some of these activities are shown in appendix C and they were selected due to their relevance to double integrals. Moreover, the GeoGebra activities included sketching quadric surfaces such as paraboloids, spheres, planes, and determining the intersection of these surfaces. These activities were accompanied by students' hand sketches of the same surfaces and their reflections on the differences between the sketches they produced, and those generated by GeoGebra. Some of the results of the activities in appendix C are shown in figure 1 and 2. Figure 1a) shows the intersection of a cone and a plane, while 1b) shows the intersection of a hemisphere and a paraboloid, as well as their resulting xy projection. Different tools in GeoGebra allow students to explore different ways of visualising surfaces.

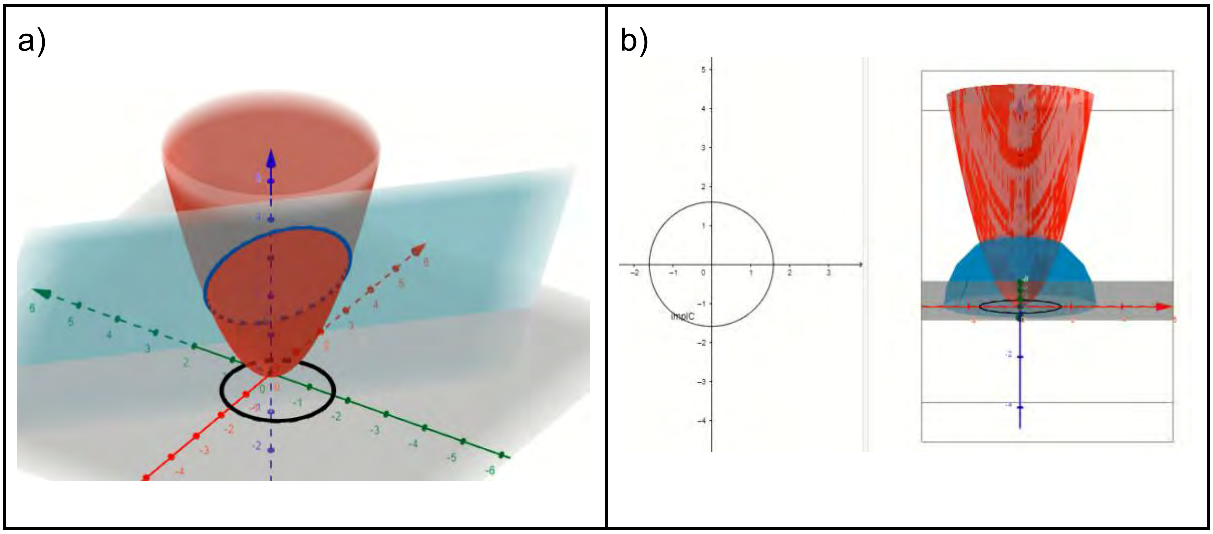

Fig. 1. GeoGebra activities showing intersection of different surfaces

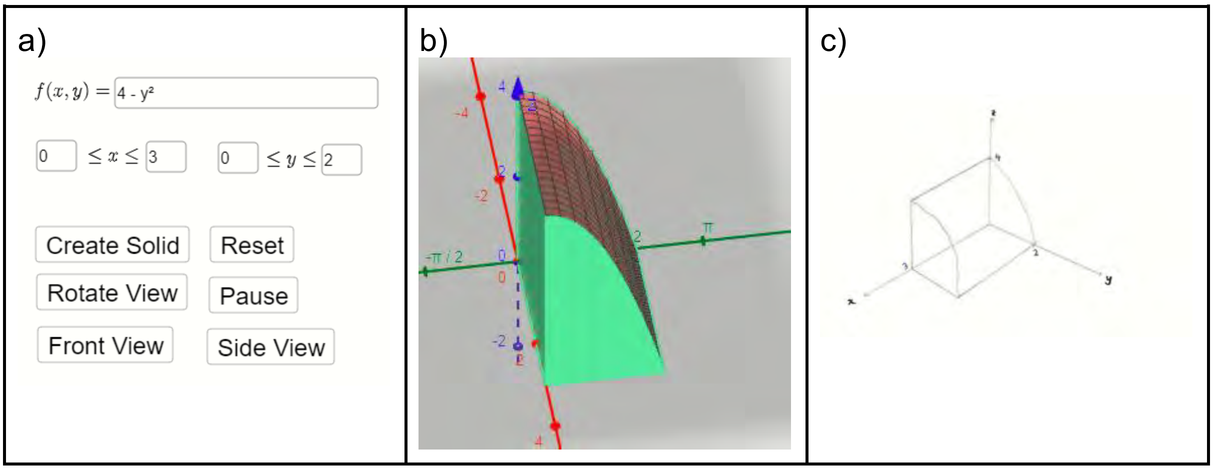

Fig. 2. GeoGebra activities used to help students sketch solids from the pre-test

Although we formally introduced students to GeoGebra in week 3, Some students were observed to be using GeoGebra for at least 4 weeks before it was introduced formally into class. After a week of activities, a GeoGebra assignment was given to students (appendix A). After the intervention with GeoGebra, we gave students a post-test investigating the impact of GeoGebra on their visualisation abilities and their interpretation of the double integral thereof.

3.3 Post test

The post-test required students to perform similar tasks to those of the pre-test. It consisted of a 10 mark question which required students to sketch the solid $\int\int 1 - x^2 dA$ over the triangular region given by $0 \le y \le 1 - x, 0 \le x \le 1$ and its projections. The test was given to the whole class in the presence of 121 participants.

The quantitative data from pre-test and post-test results were analysed using descriptive statistics. Thematic analysis of the qualitative data from the GeoGebra assignment was performed, and several reflections from students were ranked. Content analysis of the test question was also performed to understand the approach, ability, and presentation of students' sketches. The next section reports on the results and findings of the tests and students' reflections on the process and the importance of visualization tools like GeoGebra in understanding and solving double integrals problems.

4. FINDINGS AND DISCUSSION

In this section, we present the results of the pre-test and post-test, students' activities in GeoGebra as well as their reflections upon using the software. We further draw on the literature and Vygotsky's social constructivist perspectives to discuss our findings.

4.1 Pre-tests 1 and 2 and post test scores

Table 2. Descriptive statistics for tests

	Mean	Median	Mode	Standard Deviation
Pretest 1	5.28	5	10	3.34
Pretest 2	3.7	4	4	2.58
Post Test	5.07	5	7	2.77

The data suggests that the use of GeoGebra has contributed to a more varied performance among students, with the mode score shifting and a more balanced distribution of scores. The use of GeoGebra to teach double integrals may have influenced the results, particularly if the students were not familiar with the software or if the use of technology was not integrated effectively into the course. Perhaps students should have been supported more through their introduction of the software and collaborative peer work should have preceded the individual assignment. We will continue exploring ways to effectively integrate GeoGebra into the teaching and learning of double integrals and to ensure that students receive adequate support and practice in using the tool.

Pre-test 1 is equivalent in content and cognitive level to pre-test 2 however since written on different days little details were changed to preserve the integrity of the test. Table 3 outlines students' results of pre-test 1 and pre-test 2.

Table 3. Pretest results

Questions	*Total marks*	Pretest 1				Pretest 2			
		Students results				*Students results*			
		3	2	1	0	3	2	1	0
1.(a) Sketch region of integration	2		82%	0%	18%		70%	0%	30%
(b) Setup integral with order dxdy	1			54%	46%			24%	76%
(c) Setup integral with order dydx	1			43%	57%			48%	52%
2(a) Sketch the 3D solid	3	39%	4%	5%	52%	12%	3%	58%	27%
(b) xy projection	1			52%	48%			33%	67%
(c) xz projection	1			41%	59%			9%	91%
(d) yz projection	1			46%	54%			15%	85%

Table 3 shows that the majority of students from both tests were able to sketch the region of integration with 82% and 70% getting the correct regions for pre-test 1 and 2 respectively. Their understanding of the relationship between the region sketched in 1(a) and the double integral setup was further probed in the subsequent sub questions 1(b) and 1(c). Despite their success in sketching the region of integration, their success fell short when setting up the limits of integration and this is an indication that not all students were able to interpret the region to sketch the limits of integration. This is usually challenging to students who struggle to interpret inequalities and those who do not understand the geometric interpretation of a double integral. Question 2 of the pre-test gave students a double integral and required them to sketch the 3d solid as well as the projections onto the 3 coordinate planes. 57% and 85% of students from pre-test 1 and pre-test 2 respectively failed to sketch the 3d solid. The results confirmed what we already suspected – the traditional approach to teaching double integrals is not effective in helping students visualise 3d objects.

We then introduced GeoGebra to improve students' visualisation and sketching skills. This introduction was done in a supportive way and students who had not used GeoGebra before were guided through the use of the software. In addition students were encouraged to collaborate with each other in their experience of this new software and new pedagogical approach. In figure 1, the GeoGebra tasks are illustrated.

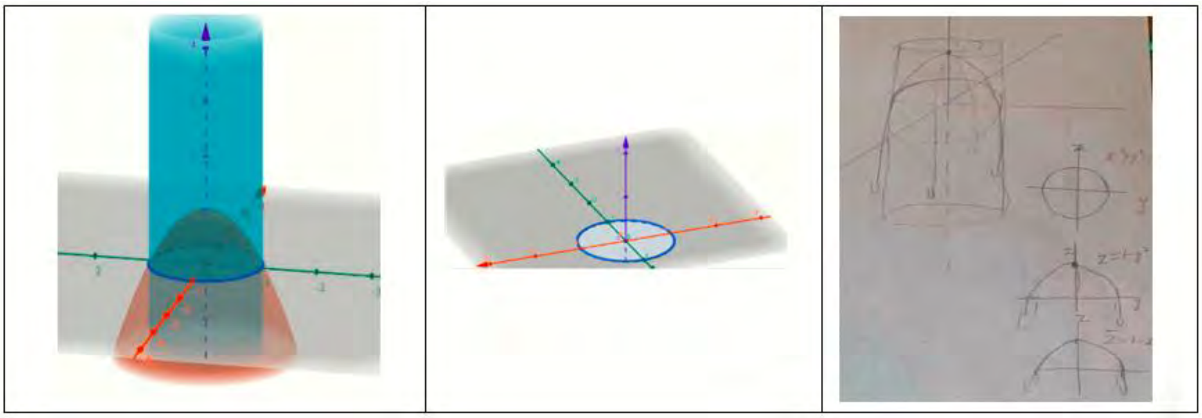

Fig. 3. GeoGebra Activities

Figure 3 is an example of an intersection of two surfaces, a cylinder and a paraboloid. The figure shows the intersection of the two surfaces and a student's sketch of the surfaces as well as the projections onto 3 coordinate planes. It is challenging for students to identify the intersection of these surfaces, and often their resulting projections onto a coordinate plane. These activities allowed students to easily translate the GeoGebra results to sketch the projections and to set up double integrals. Working back and forth between GeoGebra and hand sketches allow students to develop representations of 3d surfaces on a 2d paper. The constructions made during this process enable students to easily draw surfaces in future, visualise projections onto different planes, and to easily isolate intersection curves. This is an illustration of student centred pedagogy with students using technology to enable their own learning.

4.2 Students Reflections

In the qualitative portion of our study, we explored students' reflections on the role and value of visualization tools, such as GeoGebra, in improving their understanding of double integrals. The last task on the GeoGebra assignment required students to discuss the challenges, share insights gained and reflect on their use of GeoGebra. We categorized and tabulated their responses by frequency, as depicted in Table 4.

Table 4: Students reflections on their use of GeoGebra

Description	Frequency
GeoGebra improves visualization	44%
GeoGebra assists in identifying intersections	11%
GeoGebra aids in understanding the region of integration	8%
GeoGebra enhances comprehension of double integrals	8%
GeoGebra facilitates problem-solving	8%
GeoGebra supports determining limits of integration	7%
Grasping GeoGebra's functionality proved difficult	4%
Effective utilization of GeoGebra was learned	3%
GeoGebra improves sketching abilities	3%
GeoGebra enables projection of surfaces onto planes	2%
GeoGebra permits manipulation of graphs	2%

The data suggests that the participants benefited in various ways from the GeoGebra activities. The largest percentage (44%) reported that GeoGebra improves visualisation especially for 3d surfaces and 11% noted that it assists in identifying intersections. Other students indicated that it helps them understand the region of integration, intersection between surfaces, and develops an understanding of double integrals. Some participants noted that even though it was challenging to understand how GeoGebra works for advanced computations, it was a fun exercise that allowed them to manipulate graphs and therefore improved their sketching skills. Some also commented that visualisation tools like GeoGebra aid in visualising formulas that are required to be memorised. They added that they were able to see “what mathematics is doing instead of just merely applying formulas” , and hence the theory of double integrals made sense.

4.3 Post test

The data in table 5 outlines students’ performance in the post-test. Having done activities on GeoGebra to improve visualisation, students were tasked to sketch the 3d solid and its projections onto 3 coordinate-planes, as well as to set up the integral in the order dydx. In sketching a 3D solid, students were awarded 4 marks as opposed to 3 marks from the pre-test because the solid had multiple points of interest in the 3 coordinate planes. This is further verified by students’ poor performance in sketching the yz projection.

Table 5. Post Test results

Questions	*Total marks*	*Post test*				
		Students results				
		4	3	2	1	0
1.(a) Sketch the 3D solid	4	15%	10%	28%	12%	35%
(b) Setup integral with order dxdy	3		75%	0%	0%	25%
(b) xy projection	1				75%	25%
(c) xz projection	1				48%	52%
(d) yz projection	1				0%	100%

Upon examining the post-test results, it is evident that the introduction of the GeoGebra tool has had a varied impact on the students' understanding and performance. In sketching the 3D solid, the percentage of students scoring full marks has significantly decreased in the post-test (15%) compared to the pre-tests. However, the distribution of scores is more balanced, indicating that although students may not have mastered this concept, they have moved away from complete non-understanding. The introduction of GeoGebra also appears to have helped some students to better visualize 3D regions, but additional practice and reinforcement may be required. Although sketching solids remains a challenge, the introduction of GeoGebra seems to have greatly benefited students in setting up the integral with the order of $dxdy$. The percentage of students scoring full marks has risen significantly to 75%. This suggests that the tool has helped deepen students' understanding of determining limits of integration and changing the order of integration. This is further substantiated by students' reflections to that effect.

For projections on the coordinate planes xy, xz, and yz, the xy projection results are very positive, with 75% of students scoring full marks. This indicates that the visualization tool has been effective in helping students understand this concept. However, the results for the xz and particularly the yz projections are less encouraging. The yz projection seems to have been particularly challenging, with all students failing to score any marks. This suggests that the tool may not have been as effective in illustrating these types of projections, or that students need more time to become familiar with using it.

5. CONCLUSION

This study's focus on addressing misconceptions has significant implications for mathematics and engineering educators as well as the professional practice of graduates. Misconceptions in double integration, in particular, also affect students' performance in other sections of vector calculus such as line integrals, surface integrals and Stokes' Theorem, making it equally important for teaching to focus on these misconceptions to improve performance in vector calculus.

The primary objective of this study was to harness the potential of GeoGebra, aiming not only to enhance students' motivation in vector calculus but also to cultivate their critical thinking through the integration of software with other course activities. This approach enabled students to discern meaningful connections between theoretical concepts and applications, facilitating their comprehension of fundamental principles through the effective utilization of graphs. Furthermore, this approach aligned with Vygotsky's perspectives on students independently and collaboratively constructing meaning through engaging in meaningful activities, thus fostering a deeper and more holistic understanding of vector calculus.

Overall, the data suggests that GeoGebra is a useful tool for enhancing visualization, problem-solving, and understanding of complex mathematical concepts. However, the software may have a steep learning curve and may require a significant investment of time and effort to use effectively. It is suggested that vector calculus educators liaise with first year calculus educators to discuss the introduction of this software into first year calculus in a more supported and integrated way and to work together to address misconceptions that develop from students' prerequisite knowledge. Caution should be exercised to carefully integrate the software into the activities of the course and engage all students to participate in all activities of the course. Lauten and Ferrini-Mundy (1994) caution that technology should be used appropriately and not seen as a panacea for all student struggles.

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APPENDIX A: GEOGEBRA ASSIGNMENT

Title: Exploring Double Integrals with GeoGebra

Objectives

- To familiarize students with the concept of double integrals and their applications in finding the volume under a surface in 3D space, using GeoGebra as a visualization tool.
- To deepen students' understanding of double integrals, the process of determining limits of integration, changing the order of integration, and calculating volumes under surfaces. Additionally, students will explore the intersection of quadric surfaces in 3D using GeoGebra.

Task:

Using the GeoGebra software (https://www.geogebra.org/3d?lang=en), complete the following:

1. Consider the following surfaces: $x^2 + y^2 + z^2 = 1$ and $x + y + z = 1$.
   a) Graph the functions in GeoGebra.
   b) Determine the curve of intersection in GeoGebra.

2. Given $x^2 + y^2 + z^2 = 4, z \geq 0$.
   a) Graph the assigned function in GeoGebra.
   b) Determine the appropriate domain for the double integral.
   c) Calculate the volume under the surface using double integrals in GeoGebra.
   d) Verify the result by calculating the volume by hand.

3. Consider $z = 1 - x^2 - y^2,\ x^2 + y^2 = 1,\ z \geq 0$,
   a) Graph the assigned functions in GeoGebra.
   b) Determine the appropriate domain for the double integral.
   c) Calculate the volume under the surface using double integrals in GeoGebra.
   d) Rewrite the double integral in c) with the order of integration changed (Determine the new limits of integration and explain the reasoning behind the changes).

4. Present the results of the above and discuss any challenges faced, insights gained, and reflect on the process and the importance of visualization tools like GeoGebra in understanding and solving double integrals problems.

APPENDIX B: PRETEST 2

1. $\mathbb{R}$ is the region bounded by $y = x,\ y = 1 - x$, and $x = 1$.

   (a) Sketch the region $\mathbb{R}$.

   (b) Use your sketch to setup the integral used for finding the area enclosed by $\mathbb{R}$ such that integration with respect to x is first before integration with respect to y.

   (c) Now setup the integral used for finding the area enclosed by $\mathbb{R}$ such that integration with respect to y is first before integration with respect to x.

2. (a) Sketch the solid S whose volume is described by

$$\int_0^{\frac{3}{2}} \int_{2x}^{3} (\sqrt{9 - y^2})\,dy\,dx$$

   (b) Sketch the projections of S on the three major planes.

   $\boldsymbol{xy - plane}$

   $\boldsymbol{xz - plane}$

   $\boldsymbol{yz - plane}$

APPENDIX C: GEOGEBRA ACTIVITIES

Some of the activities from the course handbook and tutorials:

18. Sketch the region in $\mathbf{R}^2$ over which the integral $\int_0^1 \int_{x^2}^{x} xy^2\,dydx$ is evaluated.

19. Sketch the solid whose volume is described by $\int_0^3 \int_{-\sqrt{y}}^{\sqrt{y}} (3-y)\,dxdy$

20. For each of the following, describe and sketch a solid whose volume is given by the repeated integral:

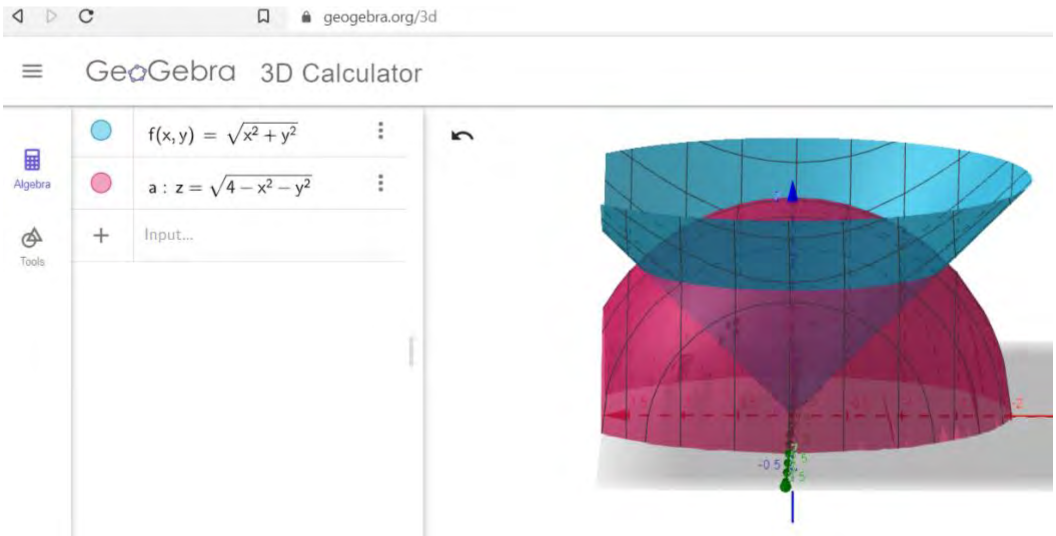
a) $\int_{-2}^{2} \int_{-\sqrt{4-y^2}}^{\sqrt{4-y^2}} (5-x-2y)\,dxdy$ b) $\int_0^1 \int_x^{\sqrt{2-x^2}} (2-x^2-y^2)\,dydx$

20. In each of the cases, sketch the region enclosed by the two given surfaces in $\mathbf{R}^3$, and then express this region in terms of spherical coordinates.

a) $z=\sqrt{x^2+y^2}$, $z=\sqrt{4-x^2-y^2}$

b) $z=\sqrt{x^2+y^2}$, $z=1$

A Student using GeoGebra to sketch Question 20 (a) from the handbook.



MOVING CONSTRUCTIVE ALIGNMENT BEYOND THE CURRICULUM: EMBEDDING MENTAL HEALTH AND WELLBEING INTO THE UK ENGINEERING STUDENT EXPERIENCE

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Key Words: *Mental Health: Engineering Education: Constructive Alignment: Authentic Learning*

ABSTRACT

This paper addresses the tricky question of how the Engineering Curriculum can be better designed so as to nurture and improve the mental health of university engineering students. Since the end of the Pandemic, the UK has seen an increase in the numbers of young people aged 18-25 self-reporting mental health problems (Young Minds, 2023). Taking a wider perspective, there has been a rise of 450% in the numbers of young people informing UCAS that they have a mental health problem over the last decade (NUS, 2022). Yet, Engineering Education has the lowest rate of self-declared mental health problems on application, with 1.4% of engineering

students giving prior notice of mental health challenges compared with 3.7% of all applicants (UCAS, 2023).

In acknowledging that lower pre-reporting rates of mental health challenges are unlikely to reflect lower rates of mental illness or unwellness amongst our students, one of the driving principles of this project is to address the higher-than-average rates of attrition and failure amongst engineering students. Furthermore, in planning how the curriculum might be further enhanced so as to promote mental health, the need to develop 'authentic' engineering education experiences (Chang et. al., 2010) is acknowledged to be central to student success.

In sum, in discussing the importance of embedding mental health into the engineering curriculum, this paper contributes to academic debates around the engineering student experience. In doing so it is argued that there is a real need to extend the concept of constructive alignment beyond the curriculum and across all aspects of the student learning journey.

1. INTRODUCTION AND BACKGROUND

Set within one of the UK's largest engineering and applied science faculties in the UK, the Positive Start Project grew out of a need to address the surge in mental health problems evident in the student body following the pandemic (Smith, 2022). In seeking to enhance wellbeing across the whole faculty, the project aims to build a unique Academic Community Practice that incorporates all students and colleagues.

The first step in the project was to equip our early career academic community with the individual skills and competencies needed to build and maintain their own mental health, and in doing so to better prepare them to meet the ever-changing needs of the student body. Hence a series of face-to-face training and support events were provided for our newer academic and graduate teaching colleagues. These events used the Clifton Strengths Tool (Gallup, 2022) to provide colleagues with an opportunity to identify their individual strengths and to consider how they might best use such strengths to enhance student wellbeing, thereby improving the overall student experience.

2. FROM FOCUSING ON PROFESSIONAL HEALTH TO EMBEDDING CONSTRUCTIVE ALIGNMENT

WMG is a unique department within the University of Warwick in that it represents a leading international role model for successful collaboration between academic and the public and private sectors. Driving innovation in science, technology and engineering, the faculty has long had a strong emphasis on scholarship and constructive alignment across research, teaching and wider society. Yet, like all higher education institutions globally, the Pandemic had a marked impact on how we work. For a period of more than two years colleagues and students alike found themselves in an unprecedented situation. Quickly having to adapt longstanding, usual highly interactive and often work-based pedagogies to a 100% virtual, and then later a hybrid form, resulted in a pressured environment in which colleagues and students quickly became disconnected from each other and from the institution itself. With the usual 'on-hand' face-to-face academic expertise suddenly being only available virtually, newer colleagues and students alike struggled to adapt. Students doing their 'A' levels also became isolated to the point that those moving into apprenticeships struggled to know how to work as part of a team.

Although the Pandemic has now officially ended, the fact that for over two years life was anything but 'normal' has meant, that for many, individual wellbeing suffered. Professional health was put aside and an emphasis on 'getting through' the curricular became the norm for colleagues and students alike. Indeed, for both groups the mid-to-longer term impact that the Pandemic has had on mental and social wellbeing is only just beginning to become apparent. Media reports suggest a general increase in depression and anxiety across the Academy (Economist, 2021; González-Betancor & Dorta-González, 2020; Evans at al., 2018) including professional support colleagues as well as more senior academics (Morrish, 2019; Loissel, 2020).

Within this complex and complicated picture, the need for constructive alignment to reach well beyond the curriculum and to encompass students' previous experiences, current circumstances and future ambitions and expectations has become paramount. In acknowledging that simply focusing on 'academic achievement' is no longer sufficient to promote a positive student experience, a number of proactive steps have been taken to enhance both the student and staff experience.

3. CONSTRUCTIVELY ALIGNING THE STUDENT LEARNING JOURNEY TO ENHANCE A SENSE OF BELONGING

The need to make sure that the student learning journey encompasses far more than lectures and academic grades has meant a number of initiatives are underway. Five of these are of particular value in terms of enhancing the student experience. These are:

3.1 Evaluation of the Student Learning Journey

With over 2,000 students and just under 1,000 undergraduates (the vast majority of whom are engineering or applied science students), a critical examination of the student learning journey on <u>every</u> single course and programme is underway.

Starting with the undergraduate programmes, a series of small focus groups with students and individual interviews with teachers has begun to identify a number of previously hidden pedagogical, social and practical challenges. Such challenges differ from cohort to cohort, course to course and programme to programme. However, looking holistically across our academic portfolio it has become increasingly apparent that student concerns reach far beyond their academic grade; undergraduates in particular are concerned about the sustainability of their course, their future career and place in society.

Additionally, other more immediate issues such as the need for students to be supported in building social groups and helped to work successfully together in groups have been identified as particularly important. As each individual course is evaluated, a number of bespoke recommendations for change are made. Teaching teams are brought together and made aware of their students' perspective. From here plans for transformative educational change are put in place and enacted.

3.2 Revising & Redesigning the Curriculum

At postgraduate level in particular, there has been a long-recognised need to revise how modules are taught. The need to move from 10 credit to 15 credit modules has seen a complete revision and redesign of the curriculum. This is being accompanied by a change in the timetabling. Previously, modules were taught in week-long blocks. This is in the process of being changed, and from September 2023 a four-week long learning 'block' approach to each module will be introduced in half of our postgraduate programmes. The remaining modules are in the process of updating and the new approach will be introduced in September 2024. The effectiveness of this in terms of learning and the student experience has yet to be discovered, although in co-creating the new approach, student feedback thus far is positive.

3.3. Introducing the 'Student Hub'

One of the most impactful changes to WMG is expected to be the introduction of the new 'Student Hub'. With work just starting, a bespoke space, developed and designed for students (and co-created with students), will bring together all aspects of individual and academic support. Additionally, other student social spaces have been introduced in a number of the faculty buildings, providing students with common work-and-rest areas.

3.4 Supporting Diversity Amongst Learners

Changes in how disabled and neuro-diverse students, particularly those enrolled on apprenticeships, have been made to proactively put in place adjustments and make declaring a disability, learning difficulty and / or mental health problems, less complicated.

Supporting individual students and making sure that colleagues are aware of the diverse needs of the student body has resulted in 'flexible constructive alignment'. Rather than expecting students to adapt to the academic requirements of the curriculum, the acknowledgement that the curriculum can be adapted to meet the needs of the students has seen a positive change in how student experience university and thus in academic achievement.

3.5. Promoting Positive Change by Supporting Colleagues

In addition to supporting students, a number of proactive measures and projects are being rolled out to staff. These include:

- **Peer Mentoring**: Using an approach developed by two WMG colleagues, a Peer Mentoring Programme is being piloted across the department. Open to all colleagues to join, either as mentors or mentees, it is anticipated that by constructively aligning the needs of newer colleagues to the skills and insights possessed by more experienced staff, a more positive 'transition' into the organisation will result improved wellbeing for all.

- **Professional Practice in Teaching**: Offered in partnership with WMG'S Education Innovation Group a series of learning and teaching focused workshops are provided to colleagues from across the department. Covering a range of topics from mental health through to teaching difficult subjects, regular interactive meetings provide a safe space for colleagues to exchange thoughts and learn from each other. Additionally, colleagues are given intensive, support to work their way through the Advance HE professional standards. Workshops, writing events and internal networking provide a proactive learning support across the WMG community.

- **Staff Interest & Support Groups:** A number of staff interest-and-support groups have been introduced offering support and advice to those from different demographic groups including Male teaching staff: Female academics: LGBTQUA+ colleagues: Disabled Staff.

- **Promoting Intersectionality in the Staff Body**: An acknowledgement of the benefits that intersectionality brings to the staff body, and hence to the student experience, has seen a number of changes in the recruitment process with colleagues from industry, previously employed on 'sessional contracts' being given permanent contracts. The impact on the 'sense of belonging' and organisational loyalty experienced and exhibited by colleagues as a result of this will hopefully come to fruition over the next few years.

CONCLUSION

In conclusion, this short practice paper has begun to outline some of the actions and activities being brought into effect in WMG, University of Warwick. There is little doubt that we have a long way to go, however, with a focus firmly on embedding constructive alignment to enhance the authentic learning within a positive academic environment an improvement in the wellbeing of colleagues and students is being nurtured. Furthermore, a new academic community of practice is beginning to emerge. One in which students and staff work together to assure continued academic excellence within a strong, mentally healthy, learning community.

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Using ICT to motivate and achieve learning outcomes in live teaching of 650 students

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Keywords: *scalability, large-enrolment classes, communication skills, engineering education, undergraduate students*

ABSTRACT

This paper describes efforts and practices used in teaching a *Communication skills* course with two full time teachers to approximately 650 enrolled students. It is focused on issues including motivating students if they consider this course to be non-essential for their professional development and a nuisance in their study, achieving learning outcomes in an efficient way, and using of ICT for assessment and self-assessment of communication skills. The ways and means of leveraging ICT in achieving these goals are presented in the paper. The potential of ICT and multimedia to motivate, keep students on schedule, gain their attention in lectures and assess their knowledge is discussed, and lessons learned from six generations of students and how they influenced course re-design are elaborated.

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1 INTRODUCTION

1.1 Communication skills in engineering

It has long been recognized that engineering students need strong communication skills (Denning 1992) and it is even more so today. The engineering profession demands not only technical expertise but also the capacity to collaborate with diverse teams, interact with clients, and present complex ideas to non-technical stakeholders (Caeiro-Rodríguez et al. 2021). Engineers today work in multidisciplinary environments, where effective communication bridges the gap between different fields and facilitates the integration of diverse perspectives. Moreover, engineers frequently engage with clients, both internal and external, necessitating clear and concise communication to understand client needs, manage expectations, and deliver successful project outcomes. Effective communication, therefore, has emerged as a fundamental skillset for engineers. It is based on engineers' communication skills, which typically refer to a set of skills including oral communication, listening, writing, visual communication, decision making, conflict resolving, intercultural communication, group communication, and interdisciplinary communication (Mohan et al. 2010; Riemer 2007). According to some research, a lot of engineers spend a majority of their working hours communicating (Tenopir and King 2004).

Many technical universities offer communication skills courses as part of their curriculum, recognizing the importance of strong communication skills for success in engineering and other technical fields. Communication skills are integrated into the curriculum either as a separate (sometimes even two-semester (Caeiro-Rodríguez et al. 2021)) course with its own learning outcomes, or implicitly within other engineering courses (Winberg et al. 2020). Still, there is a prevailing perception that communication skills in engineering education are undervalued compared to technical knowledge (Willmot and Colman 2016). Engineering students often prioritize the acquisition of technical expertise, perceiving communication skills as secondary or unnecessary for their future professional roles (Alshare, Lane, and Miller 2011). This perspective stems from a traditional emphasis on mathematics, sciences, and problem-solving in engineering curricula, with limited attention given to communication competencies.

Numerous factors contribute to the hesitation or resistance of engineering students towards developing communication skills. The rigorous demands of technical coursework, heavy workloads, and time constraints may leave students feeling overwhelmed, with little incentive to allocate time and effort to non-technical aspects. Additionally, the limited exposure to communication training and lack of integration within the engineering curriculum may reinforce the notion that communication skills are not essential for engineering success.

1.2 Teaching communication skills to electrical engineering and computing undergraduates

Due to their recognized importance, communication skills are a part of the curriculum at the University of Zagreb Faculty of Electrical Engineering and Computing. The course *Communication skills* is an obligatory first-semester course worth 4 ECTS credits or approximately 100 to 125 hours of work. Typically, about 650 new students are enrolled in the course every year and the course is delivered both in English (for Erasmus students and students enrolled in the English program) and Croatian language.

The two main issues pertaining to the *Communication skills* course are that

- the ratio between the number of lecturers and students is very low (just like in many other higher education institutions and courses)
- course learning outcomes should, ideally, be assessed by evaluating them in practice, which is often difficult.

Combined, those two issues result in significant limitations related to design of teaching and assessment practices within the course and are amplified by engineering students' general lack of interest towards communication skills and focus on technical knowledge.

1.3 Objectives of this paper

In this paper, we report on the details of *Communication skills* course implementation and outcomes in context of the two main identified issues: low lecturer to student ratio and needs for an authentic assessment of learning outcomes. Due to the prevalence of those issues in today's higher education we hope and believe this will help other teachers or researchers in transferring our implementation to different settings or building upon it.

The rest of this paper is organized as follows. Chapter 2 presents more information about the *Communication skills* course: its structure, content, and implementation. In Chapter 3, key issues resulting from course implementation as well as approaches to dealing with them are described. Final conclusions are presented in Chapter 4.

2 COMMUNICATION SKILLS COURSE STRUCTURE AND CONTENT

2.1 Course topics and general structure

The *Communication skills* course taught at the University of Zagreb Faculty of Electrical Engineering and Computing has a 15 weeks structure with a 2x45 minutes lecture to cover each of the following 10 topics: e-mail communication; creating slideshows; writing a curriculum vitae; speaking, listening and solving conflicts; popular, technical, and scientific writing; negotiating and meetings; oral presentations; finding and evaluating information; key concepts in photography and video; and cultural differences. Additionally, one week is reserved for course introduction, two weeks are reserved for the midterm and final exams, and two weeks are reserved for students' presentations – pitches.

A total of 110 assignment credits can be achieved in the course. The achieved result is capped to a maximum of 100 assignment credits (for compatibility with other courses), and grades are assigned based on it with the threshold for the highest possible course grade being 90 assignment credits, and for the lowest passing grade 60 assignment credits. Course passing conditions, other than at least 60 assignment credits in total, include achieving at least 50% of assignment credits in each of course activity categories, which are: class preparation assignments (maximum 10 assignment credits), homework assignments (maximum 25 assignment credits), participation in live lectures (maximum 15 assignment credits), final course project (maximum 30 assignment credits), and final exam (maximum 10 assignment credits).

2.2 Activity categories

Class preparation assignments. Every course lecture topic has a class preparation assignment – a short assignment students should complete as preparation for the course topic of that week. Those assignments should give students basic information about a topic or point out its relevance. They are short and are designed to require as little effort in grading as possible, although they typically cannot be graded automatically. Examples of such assignments include a Moodle quiz where students should in a short text describe main differences between Microsoft PowerPoint and LibreOffice Impress, submitting a screenshot of an email account configured in Mozilla Thunderbird, or answering several questions about a video on the topic of cultural differences.

Homework quizzes. After every lecture, students should solve a short Moodle homework quiz related to the topic of that lecture. Those quizzes consist of approximately ten questions randomly selected from a larger database. Quizzes graded automatically and are aimed to help students revise basic concepts from the corresponding lecture topic.

Exams. There is little emphasis in the course on the midterm and final exam as it is difficult to assess communication skills in such a way. Both are implemented as Moodle quizzes with offered answers and are together worth 20% of the overall course credits.

Homework assignments evaluated using peer review. In order to include more practical assignments into the course, six such assignments were designed in the homework category: writing a formal e-mail according to a custom scenario, creating a slideshow with a narration, writing a narrative resume and a motivation letter for a job application, capturing a photograph and a video, and delivering a short presentation – pitch. All those assignments are graded by students (peer review) and aim to reflect something engineers are likely to face in their professional practice. Peer review is used for evaluating those assignments not only to achieve scalability and grade all assignments in a limited time, but also to make students aware of their peers' approach to the same assignments and to foster their critical thinking.

Peer reviews are performed using structured evaluation criteria – typically about 10 questions about the graded assignment with 3 to 5 offered answers. For every assignment, every participating student can submit their own assignment and evaluate assignments of up to five other, randomly selected students. The assignment credits each student gets for their submitted assignment are based on the average number of assignment credits obtained through peer reviews of their work, excluding the worst and the best evaluation. A small percentage of assignment credits is achieved for peer reviewing other students' assignments.

Technically, peer review is conducted by having students upload their assignments to OneDrive and submit the public access link in a Moodle activity. All submitted links are downloaded using Linux *wget* command and made available to students under randomized names through one of the Universities servers. Students are sent an email with a list of five links to assignments they should peer review and they can evaluate each of those five assignments in one of the five corresponding Moodle activities. The evaluations submitted by students are finally checked by course lectures. A percentage of randomly selected assignments, as well as assignments with large discrepancies in their evaluations are manually checked and assigned assignment credits by course lecturers. If assignment evaluation significantly diverges from its objective quality, then the student who evaluated the assignment receives no assignment credits for the corresponding homework assignment.

Some properties of submitted assignments are evaluated automatically – for example, presence of audio narration in a slideshow, and the obtained information is used as another benchmark of peer review quality during lecturers' controls.

Pitching is an activity conducted in a slightly different manner than other homework assignments. Pitching is introduced in the course to reflect a need of engineers to present their idea to an audience in a limited time (*elevator pitch*). It is graded by students, but right after it was performed in front of a live audience – other students from the same group – using AudIT audience response system (http://audit.altii.online). Since there are too many students to enable each of them to deliver a pitch in front of the whole lecture group, students of each lecture group are divided into groups of five members. Each group has approximately three weeks to prepare a pitch as a one-minute presentation about something they would like to change at their institution and one member from each of those groups will be chosen by the course lecturer to deliver the pitch. Assignment credits are assigned in part by course lecturer and in part by the audience as the average number of assignment credits for that group. Assignment credits are afterwards distributed among group members so that students within a group can award assignment credits within a group based on group members' contributions.

Participation in live lectures. Since live lectures are held in groups of between 200 and 250 students, maintaining students' focus is challenging. To help with it, AudIT audience response system is used. AudIT enables classical audience response system features including some innovative features like grouping textual answers to questions based on text similarity or redirecting textual answers to other applications.

AudIT is in live lectures used mostly for two kinds of questions: questions in which only correct answers result in assignment credits, and questions in which an opinion is asked for, so any meaningful answer will result in assignment credits. Both types of questions are used to maintain students‘ attention, while questions with correct answers are used, additionally, to facilitate retention. Students can also use audit to pose questions, anonymously or not.

Final course project and its alternatives. The final course project is the single course activity with most course assignment credits associated to it (30). In its default form it is a two-minute video presentation about a student's topic of interest that they hope to work on in context of later projects and their bachelor thesis. This short video presentation should be a demonstration of students' developed ability to find and evaluate information and communicate it in an understandable and pleasant way. Students, however, are also offered final project alternatives which are more aligned with course learning outcomes but also more challenging. Students have at least two alternatives to the final course project.

The first alternative is for them to independently organize and deliver a lecture on a topic of their choice, of at least 30 minutes in duration in an institution of their choice (for example, a library or high school) in front of an audience of at least 20 people. This is a practical way of practicing or proving one's communication skills since students must organize everything themselves and finally submit a video recording of the lecture as proof.

The second alternative is to take part in a community-based service learning cooperation established with the *Institute for Youth Development and Innovativity* where students develop simple hardware projects with technologies like *micro:bit* (https://makecode.microbit.org/) and *mBot* (https://www.makeblock.com/pages/mbot-robot-kit) and teach them to elementary school pupils. While this is more demanding than the final course project, it is beneficial for students and for the community.

3 RESULTS, OUTCOMES AND CHALLENGES

The *Communication skills* course has been held in its described form since 2016 with slight changes and improvements implemented every year based on students' feedback as well as lecturers' feedback and impressions. Every year, students are at the end of the semester asked to write their opinions on specific course elements like peer review and final course project and to provide general feedback about the course in the final survey. The survey is not anonymous so that participating in it can be rewarded with a small amount of assignment credits, but it also includes a separate fully anonymous activity where students can submit anonymous feedback if they feel more comfortable that way. On average, approximately 550 students would fill in the feedback survey and approximately 15 would comment in the anonymous part of the survey.

Key observations obtained by course lecturers' reports and students' final course survey responses over the last three years of the course, as well as lessons learned and changes introduced to the course based on them are listed here:

1. **Using an audience response system is helpful for both lecturers and lecture audience**. Typically, about 75% of students enjoy using AudIT or report that using AudIT helps them to remain focused on the lecture. An additional feature of the AudIT audience response system that students would like is instant feedback about the assignment credits they receive for their answers. Since AudIT is designed not to force a lecturer to prepare their questions or correct answers in advance, this feature is currently not supported, but will be implemented so that the system prompts the lecturer for the correct answer to the current question before advancing to the next one. For lecturers, AudIT, or an audience response system in general, is essential for live lectures since it is impossible to engage such a large audience without it. Students only occasionally engage in submitting inappropriate answers or content. The flexibility of the AudIT tool allows course lecturers to use ad-hoc questions, which the lecturers find useful for adapting the course of a lecture.
2. **Most students prefer the minimal effort approach and few of them (~2%) choose activities like final project alternatives** - a self-organized lecture or the community-based service learning opportunity. Furthermore, approximately 20% of students do not participate in pitching. Students report that they find such activities interesting but avoid them because they require more work or because they do not feel ready to pitch in front of such a large audience. Students who do take part in such activities typically report being most satisfied with their outcomes, since they get to share something they like with an audience that is most appreciative of their work (lecture audience or elementary school pupils who typically enjoy such hardware projects). Still, motivating additional students to do more than is required from them in a non-technical course will probably remain a challenge.
3. **Some students dislike peer review**, but this percentage is now below 5% and has a declining tendency. Factors that helped in reducing the percentage of such students over the years are: better elaboration of peer review grading criteria; providing examples of good and bad assignments; awarding assignment credits for peer review faster; providing students with their peers' textual comments as feedback; and enabling a transparent procedure for re-grading assignments in case students think they were unjustly graded in per review. A small percentage (~1%) of students are affected by the rule that they will lose all assignment credits if they evaluate another student's assignment not in line with its objective properties. Overall, peer review is another important element of the course both for achieving its scalability and target learning outcomes.
4. **Students appreciate fast feedback on submitted assignments and achieved assignment credits**. This was one of the most common concerns raised by students in the final course survey. Most delays in assignment credits' updates were caused by the need for the lecturers to check peer reviews with significant differences in their evaluations and course lecturers' perspective, manual checking of peer reviews is one of the most time-

consuming tasks in the course. Further automation of some peer review procedures on the lecturers' side helped in dealing with this issue and improving the assignment credits' update time over the last three years.

5. **Still, students dislike too many email notifications regarding assignment credits**. Those notifications are automatically sent and, given there are more than 60 activities associated with assignment credits in the course (a class preparation assignment, assignment credits for participating in live lectures, homework quiz, and homework assignment for every week), they are sent often. A relatively simple solution to this issue is automatic sorting of emails related to assignment credits updates, but this must be implemented by students in their mailboxes and in a way that won't make them completely unaware of them.
6. **Students are generally satisfied with the course**. Overall, a lot of students submit positive comments about the course and its implementation and appreciate lecturers' efforts.

4 CONCLUSIONS

This paper describes the structure, key technologies and implementation results of a Communication skills course held at the University of Zagreb Faculty of Electrical Engineering and Computing. Two key challenges regarding the course are its low ratio of lecturers to students and implementation of activities that can assess students' communication skills in an appropriate way but using limited resources. Technologies used to achieve this (Moodle, AudIT audience response system, and custom software support for peer review) all positively affect course outcomes, as indicated by students' feedback, but are also essential from the lecturers' perspective. Those technologies and approach taken in the course seem to be sufficient to offer a quality *Communication skills* course, yet additional measures are needed to foster students' interest and increase course engagement.

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Developing a Flexible Materials Testing Course Concept for Future Engineers

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***Keywords**: undergraduate teaching, material science, mechanical engineering, course design, innovative teaching*

ABSTRACT

Engineering students as future maker of things will face the challenge of keeping pace with rapidly evolving technologies and staying up-to-date with the latest innovations in their field. To cope with these demands a flexible course concept is developed for an undergraduate Materials Science lab course: Materials Testing at HTW Berlin based on a blended learning teaching concept implementing inverted classroom lecture scenarios. High quality micro modules are defined that may individually be combined or restructured and therefore offer sufficient flexibility to match the individual scientific background of the lecturer, the course learning outcome, main study subject or actual need based on recent developments. The Moodle course offers different teaching materials, such as micro-lectures, guided questionnaires, lecture and lightboard videos, H5P-activities, etc. Lecturers will find detailed information on the course concept but independently decide on the main

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aspect of their individual teaching and are therefore granted time for various activating methods in class. With providing well-arranged individual work packages the pressure especially for lecturers from industry -who are teaching on their full time jobs- is relieved and they have more time to interact with students involving them in future common engineering challenges.

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1 INTRODUCTION

To meet the demands of rapidly evolving technologies and stay updated with the latest innovations in their field, engineering students face the challenge of keeping pace. At HTW Berlin, an undergraduate Materials Science lab course (Materials Testing) is in the ongoing development of a flexible course concept to address these demands. This concept incorporates a blended learning teaching approach, using different teaching methods .

1.1 Teaching methods and grading

Teaching methods suggested are based upon a blended learning teaching approach such as the inverted classroom method [1], [2] just in time teaching [3], peer instruction [4], peer reviewing [5], fully online teaching and also in-front teaching.

The "inverted classroom" teaching approach [1], [2], [6] involves students studying the subject matter on their own and then using class time to discuss any questions and work on hands-on lectures or exercises. Peer instruction, as described by Mazur [3], may used to assess learning progress before each class. This method of blended learning is effective and utilizes scientific peer-to-peer lecture films, micro module lectures, and different teaching materials, such as hands-on problems, lecture videos, lightboard-lectures, worksheets, mind maps, glossaries, guided questionnaires, interactive learning material (H5P), 360° virtual lab experience and online tests. All materials cater to different learning styles and enable students from different backgrounds to study online equally. The teaching materials were contributed with intensive student counceling during material science projects and colleagues to ensure high teaching standards.

Grading and assessing students' learning outcomes may be conducted as portfolio, single exam or combined assessment technique as long as the grading system is directly connected to the course learning objectives and not just a series of separate assignments, as noted by Carberry et al. (2012) [6]. Still, educators face challenges in grading and reporting student learning, as clear thinking, careful planning, excellent communication skills, and a focus on student well-being are needed to develop effective grading and reporting processes [7], [8]. Shifting the focus to standards and making criteria secondary could lead to significant advances [9]. Therefore, the a portfolio grading seems to be most appropriate to assess students` progress and competencies when preparing them for future engineers

1.2 Course setting

At HTW Berlin, Material Science is a mandatory course taught in the first and second semester of undergraduate programs (5+5 ECTS) such as mechanical engineering, automotive engineering, and economical engineering, using a "design-led" teaching approach [1]. The goal of this approach, particularly in the first year, is to engage students with the question "What is the objective of the design?" from the start of their studies. In contrast, the traditional "science-led" teaching approach starts with the physics and chemistry of materials, progressing from the atomistic to the macroscopic properties, and often loses the motivation for design challenges.

Therefore, the second semster comprises of a practical lab course: Materials Testing (5 ECTS). Through this practical approach, students learn to critically examine materials, properties, alternative materials and processes, as well as the underlying physics and chemistry. While understanding the theory of material science is necessary, the focus of teaching should be to educate students and prepare them for their role as makers of things, as advocated by Ashby, Shercliff, Cebon (2013) [10].

This paper outlines the course structure, explains the individual combination of lecture materials and refers to possible assessment methods.

2 MATERIALS SCIENCE LAB COURSE DESIGN

Besides the engineering courses 12 other study subjects require material science lab skills at a later point of the curriculum such as restauration, textile design and applied IT. However, capacity of lecturers and lab time are not sufficient it is necessary for students to be well prepared before entering the materials science lab. The Moodle based virtual lab online course offers both, the opportunity to study self-directed and a profound materials base for lecturers who are teaching undergraduate materials science. Following the OER (open educational ressources) the course will be available to all lecturers teaching materials science at HTW Berlin. At a later stage the course design may be open to the www public.

Studens virtually “walk” through the following topics as virtual lab rooms:

- Ultrasonic testing
- Hardness testing
- Charpy test
- Tensile test
- Heat treatment of steels
- Metallurgy
- Light microscopy

They can experience the testing machines as well as analytical equipment. The main functions are explained and theoretical background given (Fig. 1).

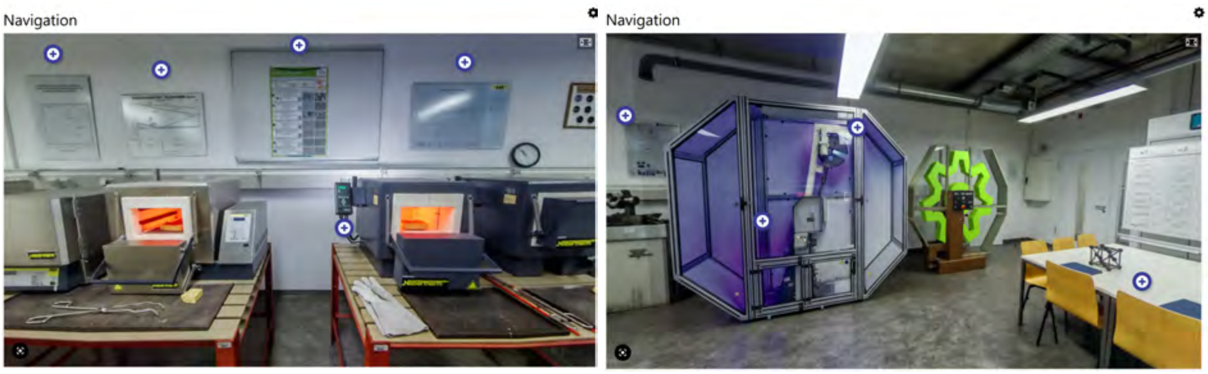

Fig. 1. 360° virtual material science lab

Micro lectures are arranged along with lightboard lectures and lecture videos within the 360° lab. Additionally, all activating materials for self-assessment are implemented (purple crosses). The 360 °C virtual lab course (Fig. 2) comprises of :

- micro lectures
- interactive activities
- guided questionaires
- glossaries
- lecture videos
- lightboard lectures
- tests
- interactive assignments

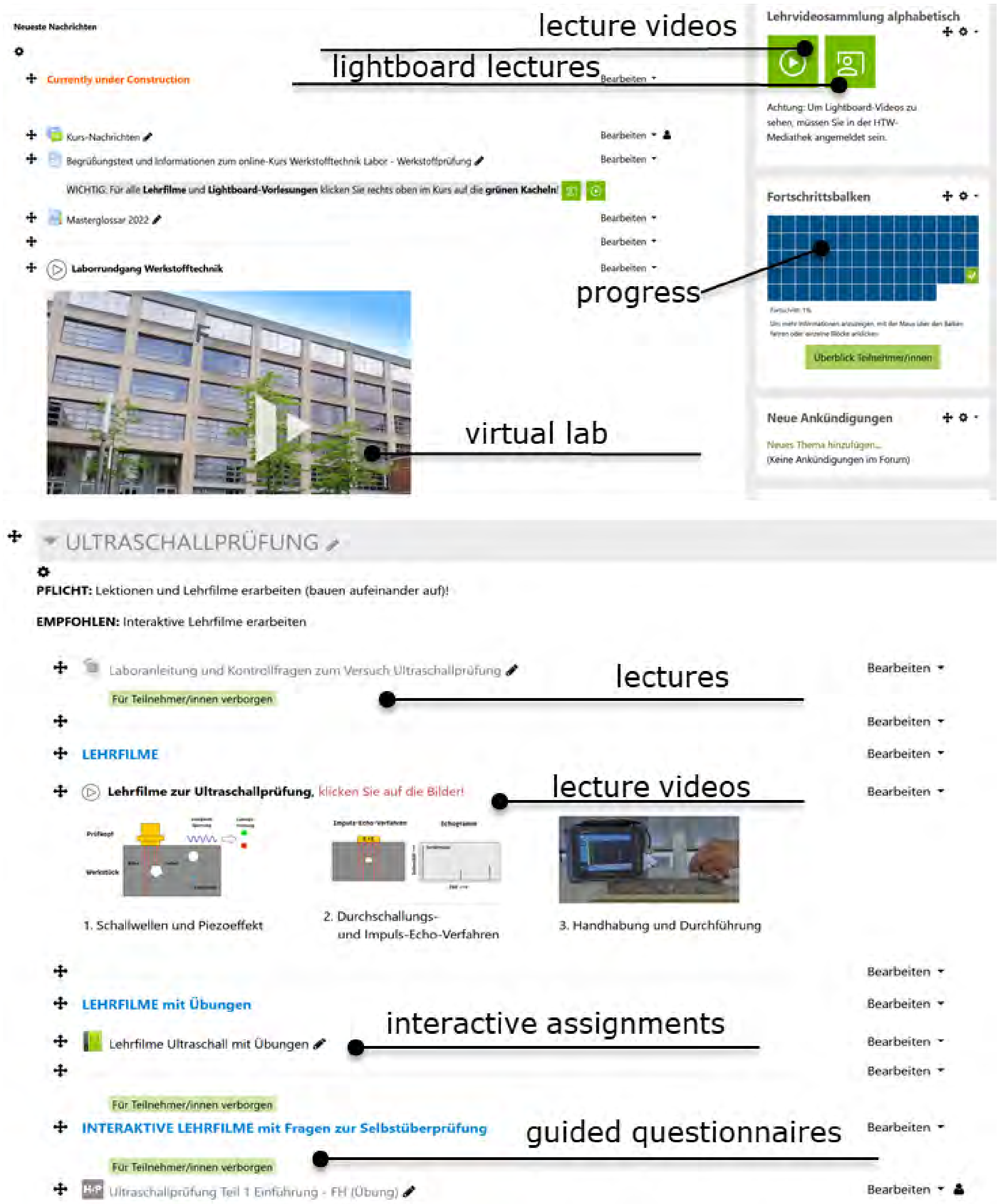

Fig. 2. Moodle course design

3 BENEFIT FOR LECTURERS

The high quality micro modules are always arranged the same throughout every theme so that students easily manage the Moodle-format [6] and know exactly where to find which information (recommendation – graded activities – micro lectures – lecture videos – interactive videos – assignments – gloassaries – guided questionnaires – additional OER). Lecturers will find detailed information on the course concept but independently decide on the main aspect of their individual teaching and are therefore granted time for various activating methods in class.

All micro teaching materials may individually be combined or restructured and therefore offer sufficient flexibility to match the individual scientific background of the lecturer, the course learning outcome, main study subject or actual need based on recent developments. Lecturers may individually pick, sort and alter the teaching materials within the lab rooms as it suits the individual teaching method allowing for maximum freedom of teaching (pick and place). At the same time the all teaching ressources are valid and do not have to be prepared beforehand. This allows for activating methods, discussions, role plays, micro projects and precise questions&answers in class.

Rooms as well as individual teaching material may be opened or closed so that the content is aligned with the courses` learning outcome. With providing well-arranged individual work packages the pressure especially for lecturers from industry -who are teaching on their full time jobs- is relieved and they have more time to interact with students involving them in future common engineering challenges. However, students need to be advised thoroughly how to work the course and its grading. Right from the beginning lecturers point out the importance of individual work and contribution of every student throught the semester.

4 EXAMPLE OF WORKLOAD

The lab course is suitable for individual studying (self-directed), fully online studying, inverted classroom teaching methods, just in time teaching following the blended learning approach. It may also be ressource for present teaching using different teaching methods and assigments adding to students` total workload as depicted in a possible example outlines in Fig. 3.

Standards-based grading assesses students' achievement of the course's learning objectives, providing them with personalized feedback that is clear and meaningful in terms of meeting the course's objectives and helping them identify their weaknesses in the course [10]. Therefore, the course design offers a portfolio grading and assigns competencies but criteria based grading may be applied when necessary.

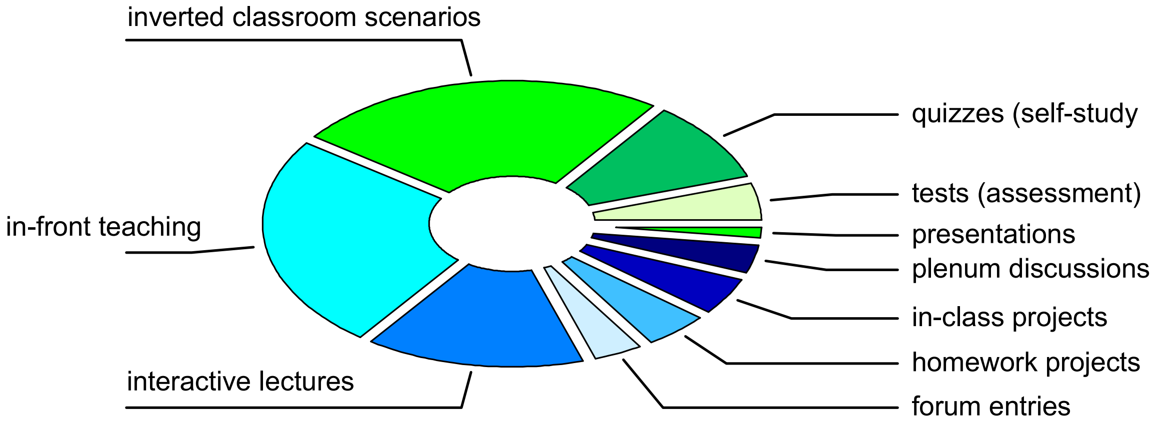

Fig. 3. Moodle course design

Table 1 shows an example of content, teaching method and competency achieved throughout teaching the course as a blended learning course.

Table 1. Example of Materials Testing lab course: Content, teaching method, teaching material, competency and learning outcome

Topic	**Teaching Method**	**Self-study period**	**In-front/lab work**	**competency**	**learning outcome**
Ultrasonic testing	Fully online	Lectures, lecture videos, H5P, guided questionnaires	Lab	Remember, understanding, apply, analyse, evaluate	Reading and interpretation of ultrasonic test results
Hardness testing	Inverted classroom	Lectures, lecture videos, H5P, guided questionnaires, problems	Mini-project/lab	Remember, understanding, apply, analyse, evaluate	Application and Interpretation of hardness testing: Rockwell, Vickers, Brinell
Charpy test	Fully online	Lectures, lecture videos, H5P, guided questionnaires	lab	Remember, understanding, apply, analyse, evaluate	Interpret of fracture surfaces according to brittle and ductile failure
Tensile test	Inverted classroom.	Lectures, mikro project, lecture videos, H5P, guided questionnaires, problems	Hands-on problems, lab	Remember, understanding, apply, analyse, evaluate	Conduction of tensile tests (push-pull), setting up and interpretation of a stress-strain-diagram: yield and strength
Phase Diagrams	Inverted classroom	Lecture videos, Lightboard-lectures	Hands-on problems, lab	Remember, understanding, apply	Reading of the iron-carbon phase diagram
Heat treatment of steel	In-front		Plenum discussion, hands-on problems, Mini projects	Remember, understanding, apply, analyse, evaluate, create	Conduction and application of heat treatment with regard to alterning mechanical properties of steel
Metallographic analysis and microstructure	Inverted classroom	Lectures, quizzes	Mini projects	Apply, analyse, evaluate	Interpretation of microstructural graphs as result of heat treatment

5 STUDENT`S BENEFITS

Right from the beginning, students are provided with a clear understanding of how the course is structured, including content, theoretical background, self-study periods, and hands-on lab time. This knowledge empowers students to adapt their learning behavior and take full advantage of the study freedom offered. The course outline and the use of Moodle as the platform contribute to this clarity, serving as a guide for students as they work on their weekly assignments.

The assessment process is transparent, enabling independent and self-directed learning while allowing students to reflect on their individual learning progress. By combining practical and theoretical work, the course facilitates a deeper understanding of the subject matter and enhances students' study motivation. This approach also prepares students for their future roles as engineers, where they will consistently be expected to engage in practical work while possessing a solid foundation of theoretical knowledge, a skill set that students today are required to develop independently.

6 SUMMARY AND ACKNOWLEDGMENTS

A flexible curriculum is developed for an undergraduate Materials Science lab course based on a blended learning teaching concept. Different teaching methods may be applied and combined (inverted classroom lecture scenarios, just in time teaching, etc.). All teaching ressources are made available in a 360° Moodle course comprising of high quality micro modules with various teaching ressources (micro-lectures, hands-on problems, guided questionnaires, lecture videos, interactive learning material (H5P) and lightboard micro lectures). Lecturers are therefore granted time for various activating methods and project work in class. Main aspect of the course is to encourage lecturers to individually combine and restructure the content according to the courses learning outcome. The 360° lab offers joy of use to students who virtually experience the practical aspects of materials science testing with regard to self-directed learning preparing as future engineers.

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FLASH OBSERVATIONS FOR IMPROVED TEACHING QUALITY AMONG GRADUATE TEACHING ASSISTANTS IN ENGINEERING

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ABSTRACT

To maintain high quality, when teaching practical activities at scale, sufficient Graduate Teaching Assistants (GTAs) must be employed. However, their pedagogical skills are inconsistent.

This research is a pilot study to test the reliability and validity of research methods which will be scaled up in their application to the primary research to identify GTA pedagogical skills requiring further training. In the primary study, staff and GTA perspectives will be collected using surveys, and the emerging deficient skills will be further investigated using novel twenty-minute “flash” skills-based teaching observations of GTAs. Observation time will be split among the GTAs, and the focus will be on using one of the single skills identified in the surveys by GTAs across the lab rather than how an individual uses it.

This paper documents a pilot study conducted to trial a selection of three bespoke observation forms based on asking questions (i.e., the observed skills). Reflections by four observers after eighteen observations indicated that twenty minutes was sufficient time to get a fair assessment of how the observed skill was being used. The format allowed researchers to give individual feedback to GTAs who requested it and provide insight regarding the use of that skill in the lab.

The researchers identified two critical factors for the successful launch of the primary study; assessing the lab settings - to avoid significant interference with the teaching - and identifying when in the session GTAs are expected to use the observed skill– ensuring that the short observation is timed effectively.

1 INTRODUCTION

Over the years, Graduate Teaching Assistants (GTAs) have taken on a significantly larger role in higher education. As the number of enrolled students has risen, research-led universities have increasingly relied on GTAs to support undergraduate teaching. In many introductory courses and laboratory sessions, especially in STEM subjects, GTAs make up a substantial portion of the teaching staff, thus playing a critical role in educating the next generation of graduates.

This is also the case at the University of Sheffield (UoS) and, in particular, in the Multidisciplinary Engineering Education (MEE) department, as it provides engineering students with practical lab-based activities. Working at a large scale - up to a thousand students in a week for a single lab (Di Benedetti et al. 2022a) - it is necessary to employ a sufficient number of GTAs. At the same time, to retain the high-quality standard of teaching, pedagogical training is offered to all GTAs in MEE.

The current pedagogical training consists of university-wide workshops - designed to include learning theory and pedagogy in a non-subject-specific context to support GTAs across the university - and regular sessions offered departmentally specific to lab-based teaching (Di Benedetti et al. 2022b).

The faculty-wide workshops focus on introducing the GTAs to basic teaching skills: the role of a GTA in practical teaching, how to ask and answer students' questions and how to deal with challenging situations. The lab-based training consists of specific aspects of a lab session: health and safety, learning outcomes and practical requirements for operating a specific laboratory equipment/set-up.

Nevertheless, the pedagogical skills of the employed GTAs remain inconsistent. This is because the team of GTA is fluid, with more experienced ones leaving and newer ones with different prior teaching experience - if any - being recruited every semester. When teaching, this inconsistency is typically tackled by pairing more experienced GTAs with newer ones. In addition, the current departmental training could be enhanced by identifying the GTAs’ need for further development and incorporating them into the training content.

An ongoing research project in MEE aims to identify the GTA skills requiring further training by looking at multiple lenses. The perspectives of both staff and GTAs are collected through surveys to have insights into the skills that are perceived as important but that are currently lacking or insufficient. GTA skills are also assessed using teaching observation to identify strengths and common deficiencies.

By using these different lenses, the research aims to gain a comprehensive understanding of the skills that GTAs need to develop further to be effective in their teaching roles. By considering the perspectives of both staff and GTAs, as well as systematically observing teaching practices, the study can provide valuable insights into the areas where training and support are most needed to improve the quality of teaching provided by GTAs.

This study is part of the aforementioned research and specifically focuses on the initial pilot study carried out to investigate the use of a novel, "flash" skills-based teaching observation format.

2 METHODOLOGY

Pilot studies are recommended to identify any potential problems with the methods or ideas before being applied at a larger scale (Jairath et al. 2000). In this case, the validity and reliability of the new teaching observation method were tested. In particular, the focus areas for the pilot study were: 1. To ensure that the categories in the observation templates were clear, unambiguous and easy to complete in the time frame and environment of the lab; 2. Which position would be optimal for the observer to take to minimise the impact on behaviours by their presence; 3. To ensure that the data collected was fit for informing follow-up training; 4. To identify any other practical issues. Guidance into the effective use of pilot studies suggests running the pilot with approximately 10% of the expected number of participants (Connelly 2008). It is also advised that participants are representative of those who will take part in the actual study (Cohen et al. 2018). 11 GTAs were observed in this first instance who were selected because they work in the labs which would be used as part of the main study. To ensure an adequate level of experience for the observers, all observers were Senior Fellows of the Higher Education Academy (SFHEA).

To evaluate an isolated pedagogic skill across a cohort of GTAs, the traditional teaching observation templates used at UoS, which are designed to give feedback on individual teachers' performance rather than an isolated skill, were rejected. Instead, new teaching observation forms were designed which could be used to record the use of the single skill of "asking questions" by a small selection of teachers across 20 minutes of a lab session.

2.1 The Skill: Asking questions

This skill was chosen as it is frequently identified in discussions over key skills used by GTAs in supporting teaching and learning in labs (Deacon et al 2017) and due to the agency GTAs have over question design. The impact of effective questioning on student learning is also widely recognised among educators. Rather than exclusively being a means to monitor student understanding and knowledge, the effective use of questioning by the teacher has also been proven to facilitate learning and memory retention. Even operating at the lowest level of Bloom's cognitive domain (Bloom, 1984), Roediger and Butler (2011) assert that recalling information has a greater impact on learning and memory retention than studying. For "recall" to be effective for learning, feedback needs to be available to ensure the correct information is being learnt. In this way, recall questioning from teacher to student or with the teacher present to be able to correct misinformation is an important aspect of an effective learning environment and one over which GTAs have agency in the lab. Roediger and Butler's study also found that recall had more impact on long-term memory when it required "effortful processing" rather than straightforward rote learning underpinning the use of a range of questioning techniques in the lab.

Teacher questioning also provides a model to students to help them to develop an inquiry-based approach to learning (McTighe and Wiggins, 2013). Asking students questions not only promotes recall, interpretation and explanation of knowledge, it also models a reflective skill where students are encouraged to interrogate their understanding and critically reflect on how they have reached their conclusions, "a key long-term goal of education is for students to become better questioners because in the end— with much knowledge made quickly obsolete in the modern world— the ability to question is central to meaningful learning and intellectual achievement at high levels."

Studies by Black and Wiliam (1998) and McTighe and Wiggins (2013) both found that teacher questions are often based on eliciting factual recall of knowledge or were leading in the way they were framed meaning that the "effortful processing" required by the student in answering them is reduced. This research aims to see whether this assertion is true of the GTAs in the MEE labs.

2.2 The Teaching Observation

New templates were designed to observe GTA for 20 minutes and assess their "asking questions" skills. A structured approach to recording principally quantitative data with an opportunity for comments was chosen as the most appropriate for the context of the study as it generates numerical data which can then be used to identify patterns and trends and can be used to easily make comparisons between different settings (Cohen et al. 2018). Quantitative data can also be captured more quickly than written notes, facilitating the process for observers to record more information more quickly and whilst moving around the lab than if they were recording primarily qualitative comments. However, an option for additional comments, which either could explain some of the quantitative data or which could be particularly helpful to feed into the resulting training, was also included as part of the observation forms to allow for confounding factors and additional context also to be captured.

For this initial trial of the study, three forms were created to measure how questions were asked across the lab by different teachers. Each form required the name of the observer, the session, the date, the start time of the observation, the number of students and the number of GTAs. GTA names were recorded so that collected data could be given to the observed GTA if requested. Each observation began one hour after the start time of the lab to allow time to pass for the group to settle and to have started the experiment before the observers arrived. The GTAs were informed in advance about the observation taking place during their lab session, along with the name of the person observing and the form being used. The three forms were used on rotation for different labs. Each observer assigned themselves labs to observe, and several labs had more than one observer to allow for the moderation of results. Observers who were also lab leaders as part of their job only observed labs which were not their own to mitigate the impact of GTAs feeling judged or that the results from their observation would impact future work assignments to them. This approach also avoided bias on the part of the observer, which may have arisen through knowing the observed GTA. As GTAs work across labs, this was not always possible but was implemented wherever it could be.

The first form (Fig.1, top) required the observer to write the question posed by the observed GTA and also to record if the question required an immediate response (IR) or if the GTA allowed one minute or more for students to think about the answer (TT). Data were also recorded on whether the question was posed to the whole group or an individual. If it was to an individual, then the gender of the respondent was also recorded (Male/Female/Gender Neutral). Before the observation started, the observer(s) would meet the lab lead, who would tell each observer the name of the GTAs, and any other relevant details needed by the observer to carry out the study reliably.

The second form (Fig.1, centre) was a frequency analysis of the types of questions being asked in the lab. Questions were coded by the type of information sought. These included checking progress (CP), seeking analysis (SA), seeking links (SL), checking for understanding (CU), and checking prior knowledge (CPK) (The University of Sheffield 2019). The cognitive domain of Bloom’s Taxonomy (1984) was consulted as a guide to creating the code to categorise the questions. For example, “Checking prior knowledge” (CPK) is linked to recall and “seeking analysis” (SA) is linked to analysis. Observers tallied the types of questions using these categories they heard during observation. This form also required the gender of the person asked to be recorded.

Form Three (Fig.1, bottom) recorded the sequence of questions asked based on the same type categories as Form Two. In form three, the observer used the codes to record which type of questions were asked during each five-minute segment of the 20-minute observation. Gender was not recorded on this form.

Form One

Name/ number	Questions asked	Think time (TT) given or immediate response (IR) expected	To whole group	To an individual (M/W/GN/None of the above)	Other comments
Example	• How are you getting on? • What do you think? • Why do you think that happened?	IR, IR, TT	/	 M W	

Form Two

Name/ number	Checking progress	Seeking knowledge	Seeking explanation	Seeking analysis	Seeking links	To whole group	To an individual (M/F/GN/NA)	Other comments
Example	///	//	///		/	///	M, M, , GN,	

Form Three

name/number	1-5 mins	5-10 mins	10-15 mins	15-20mins
Example	SA, SL, CPK	CU, CU, CP	CP	SA

Fig. 1. Relevant extracts of observation Form One (top), Two (centre), and Three (bottom).

A total of eighteen sessions were observed over one month by the four observers. At the end of this period, individual reflections were independently submitted by each observer of their experience of the process. An inductive thematic analysis of the free text was then conducted to identify the strengths of the process and aspects which needed revision before the final study.

3 RESULTS

3.1 Observers' Reflections

All observers struggled to ensure that the observation process did not interfere with the teaching. This was a trade-off between the observer's distance from the observed GTA, the voice level of the GTA, and the background noise. In addition, it was noted that some GTAs were observed more frequently than others; this is possibly due to the limited period the pilot study was carried out and the fact that the main factor in selecting sessions was the observers' availability. Moving forward, a more strategic/inclusive approach should be adopted.

In general, all agreed that the twenty-minute duration was sufficient to observe up to four GTAs and that the short duration made the observation task "light and quick" without adding a significant workload on the staff. On the other hand, observing only a portion of a lab session meant that, at times, the skill under observation was not used. This could be seen as a lack of such skill, but it could also be that it was not necessary as part of the tasks the GTA needed to complete. To avoid misinterpretations in the future, observers should always have a prior understanding of the lab activity and correctly set their expectations regarding the required skills.

The observers agreed that all types of formats to assess "asking questions" were well structured. Form Three required additional time before the observation to gain more familiarity with the different codes. In all cases, more context about the session should be reported, and also elements perceived as pedagogically important but not strictly related to the observed skill should be noted down for feedback to the GTAs. Observers also noted that Form Three was more open to personal interpretation and harder to review, and it did not offer an insight into the "level" of questioning (the latter was also a problem for Form Two). Form One, on the other hand, offered a richer set of data from which codes and tallies can be extrapolated in post-processing. Conversely, none of the current formats was suitable to capture the appropriateness of the asked question (i.e., was that the right kind of question to ask?).

In Form One, it was possible to write down the meaning of most of the questions and to note down everything the forms asked for. The IR / TT split was useful for describing broad or targeted questions. However, observers should consider adding if a question is appropriate (i.e., was a broad question relevant for that part of the lab?). One comment on Form Two was that GTAs, who do not have many tallies, spent most of the time talking to the students during the observation, compared to GTAs, who asked a good variety of questions, from checking for progress to checking for understanding. Which questions are asked can underline the GTAs' confidence in the subject and give a good idea of the GTAs' background knowledge. In Form Three, the third form, the 5-minute intervals were useful to time the observation, making sure to observe all the GTAs within the time slot. However, the coding forms do not capture the good level of questioning by the GTAs, and some questions didn't fit any of the codes, e.g. "Do you want to try?". In general, the 'other comment' box was useful for including points of note which fell outside the direct skills the form was measuring but which were still adequate for the training.

3.2 Forms Analysis

Combining the three forms, we can detect some preliminary data, which shows scalable patterns regarding GTAs' skill in asking questions to students. In Form One, the students gave an immediate response to a question more frequently (IR, 29 out of 30 questions) compared to thinking time questions (TT, 1 out of 30 questions). There was an equal divide between questions asked to a group or an individual. The questions asked were mostly focused on analysis and comparison of results.

The results of Form Two and Form Three are summarised in Fig.2. When looking at the questioning techniques, the GTAs are more confident asking questions related to the analysis of data or methods (SA, 24 out of 68 questions) compared to questions that make connections and links to the different parts of learning (SL, 8 out of 68 questions), check students' previous knowledge (CPK 6 out of 68 questions) or students understanding (CU, 11 out of 68 questions). Additionally, students were often asked to describe their progress so far (CP, 19 out of 68 questions). However, this distribution may be influenced by the limited duration of the lab observation and the specific timing of the observation within the lab session (e.g., at the start, middle, etc.). Preliminary findings also suggest a variation in the distribution of question types across different lab activities. These nuances warrant further exploration in the final study to provide a more comprehensive understanding of GTAs' questioning techniques.

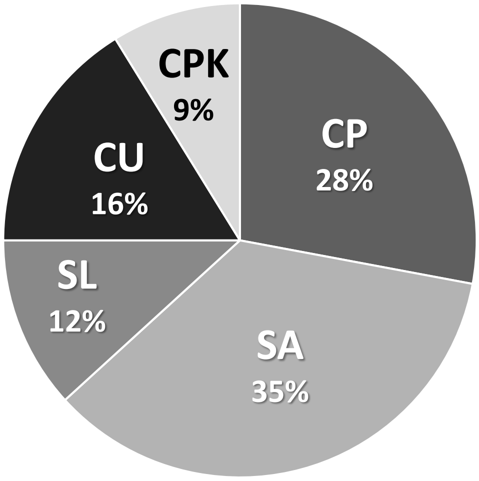

Fig. 2. Distribution of the techniques used when asking questions

4 SUMMARY

It can be concluded that the observation forms used in this pilot study have effectively recorded the use of an isolated teaching skill used by multiple GTAs in a lab context. The pilot has shown that the observation forms are a useful and effective tool to study and monitor GTAs' pedagogic skills as they capture various elements contributing to effective questioning by GTAs. For example, the level of confidence in asking questions by the observed GTAs can be deduced to some degree by the frequency of use of different types of questions. Further, GTAs' subject knowledge of the lab and competency in evaluating the student's understanding of the session and the lab procedures can be evidenced through the type of questions being asked, which were accurately captured in the forms.

The limitations of the data collected through the observation forms identified by this pilot study are mostly due to the short one-month timescale of the observations leading to only initial indications of emerging patterns, lack of strategy in the selection of labs to observe and the use of a single timeframe for the start of every observation meaning that the progression of questioning throughout the course of the whole lab could not be documented. A better understanding of the lab content by the observer will avoid the chosen focus of the observation being a skill that is not relevant to the observed lab. This knowledge will also inform the selection of the start time of the observation to ensure that the segment of the lab observed would be the time frame where the isolated skill to be observed would be most appropriate to be in use.

The pilot has proven the forms to be fit for purpose, and the manageability and improved accuracy of recording full questions are favourable to type coding in the session. Codes can be applied at a later date when more thought can be given to the appropriateness of the categories. The implications for the primary study include the necessity for a more strategic approach to ensure that they are used to the best advantage to collect an accurate overview of skills used across the full duration of the labs.

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THE “EAGLE” APPROACH TO TRAIN ELECTRICAL ENGINEERS WITH COLLABORATIVE PROBLEM-SOLVING SKILLS

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ABSTRACT

Engineering education plays a critical role in addressing the ever-increasing environmental and societal challenges, and collaborative problem solving (CPS) is a vital skill for engineers to tackle such complex multidisciplinary challenges and develop high-quality solutions. The EAGLE project at KU Leuven exemplifies CPS implementation in electrical engineering education, providing students with real-world connections and deep learning opportunities to develop teamwork, problem-solving, and negotiation skills.

This paper presents the development and implementation of EAGLE, a year-long hands-on, multidisciplinary challenge in which teams of 10-12 students design and develop an autonomous drone capable of flying to a remote landing station. It focuses on the project organization, innovative coach-based teaching and grading system, and the multi-dimensional evaluation and grading processes employed.

The insights gained from the EAGLE project can offer valuable lessons for future project-based learning initiatives and encourage the adoption of innovative teaching and learning approaches in engineering education. By sharing our experiences, we aim to inspire other educators to integrate real-world projects into their curricula, emphasizing the significance of hands-on learning, teamwork, and CPS in engineering education.

1 INTRODUCTION

Engineers are trained to become creative problem solvers, capable of applying knowledge in many domains, including mathematics, physics and computer science, to tackle complex multidisciplinary problems. Collaborative problem solving (CPS) is indeed an essential 21st century skill for stimulating creativity, and high-quality solutions, relying on ideas, experiences and information from multiple perspectives (OECD 2017). CPS entails the collaboration of two or more students to come to a unified solution for a problem by sharing and integrating ideas, skills and knowledge. It challenges both technical knowledge and social skills of students, preparing them for practical work environments where problem-solving is a collective effort rather than an individual one (Sun et al. 2020; Andrews-Todd and Forsyth 2020). Deep learning opportunities provided by CPS allow students not only to increase their conceptual understanding and content-related knowledge but also to develop these necessary social skills. In accordance with the self-determination theory, by working collaboratively towards a common goal, individuals are motivated to achieve higher levels of performance and engagement, leading to more efficient and effective problem-solving outcomes (Deci and Ryan 2000). Therefore, understanding the concept of CPS and its underlying motivation is crucial for educational and practical settings (Deci and Ryan 2000; Raes, Pieters, and Vens 2022).

The EAGLE project at KU Leuven serves as a notable example of implementing the CPS concept in Engineering education. However, it is important to note that the presence and extent of CPS tasks can vary across different engineering programs, contexts, and countries. As a result, students enrolled in certain programs or situated in specific regions may have limited opportunities to engage with CPS tasks during the initial two years of their undergraduate education. Nevertheless, within the context of engineering bachelor's programs at KU Leuven, students encounter instances of Collaborative Problem-Solving (CPS) tasks at different stages. These tasks involve applying engineering skills to develop solutions for multifaceted multidisciplinary problems. The EAGLE project, which takes place in the third year, represents the culmination of this process. It not only establishes a tangible link to society by addressing the demand for unmanned aerial systems in diverse applications but also provides students with a comprehensive and challenging multidisciplinary task. Throughout an entire academic year, students work collaboratively in teams of 10-12, showcasing their ability to solve complex problems together.

The autonomous drone project involves various domains, mainly mechanical, electrical, and software engineering. It provides valuable learning experience while assessing students' competencies through transparent scoring approaches, peer feedback, and effective guidance by a large team of teaching assistants (TAs). It is worth mentioning this project is part of the curriculum of approximately 80 students, guided by roughly 20 TAs and 9 professors.

This paper presents the employed strategy in the "EAGLE" project to promote collaborative problem-solving in engineering education. We explore the challenges that arise in such an approach and highlight the solutions, including efficient and effective guidance, and multi-dimensional evaluation. By sharing our experience, we hope to inspire other educators to incorporate real-world projects in their curriculum that provide students with valuable skills and knowledge.

2 METHODOLOGY

In this section, we will first discuss the project description given to the students, followed by how the project is supervised and finally how it is graded.

2.1 Project Description

Unmanned aerial vehicles (UAVs), commonly known as drones, have experienced significant advancements in terms of affordability and technology. These advancements have facilitated the integration of various sensors, wireless communication capabilities, and intelligent autonomous systems, thereby unlocking a wide range of innovative applications, such as maintenance inspections of infrastructure, optimizing energy management through smart meter data, and delivering essential supplies to remote or inaccessible locations, including vital medications. The widespread utilization of these smart drones, however, requires seamless integration of diverse electronic components, enabling efficient operation.

The EAGLE project at KU Leuven attracts students primarily enrolled in the electrical engineering bachelor's program. While the exact demographics of the student cohort can vary from year to year, the project involves approximately 80 students (and maximum 120 students) who collaborate in self-organized teams of 10-12. The students have the freedom to choose their team members, and there is no specific requirement for diverse backgrounds, although it is often beneficial. Students are encouraged to complement their skills by collaborating with peers who have different expertise. The TAs/coaches assist in the splitting of modules, providing guidance on workload distribution and the skills required for each module. However, the final decision on task allocation within the teams lies with the students, allowing them to take ownership of their work and make choices based on their interests and strengths.

The primary objective of the project is to develop an autonomous drone capable of navigating towards a predetermined destination, where it will provide wireless power to illuminate an LED wall. Since the precise location of the LED wall is initially unknown, the drone must navigate along a designated path marked by a series of

QR codes arranged in a regular grid pattern, represented by red lines. Along this path, the drone will encounter and overcome various challenges, such as operating under remote control, executing autonomous loitering maneuvers, and ultimately achieving full autonomous flight. A graphical representation of this mission is provided in *Fig. 1*.

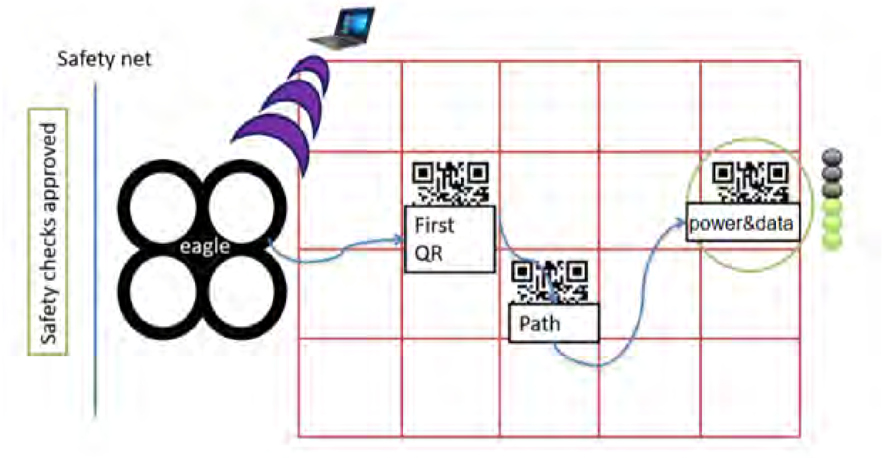

Fig. 1. Graphical representation of the EAGLE mission

The EAGLE mission is divided into multiple submodules, all of which contribute to its successful realization. These submodules are carefully designed to address specific aspects of the project and foster collaborative problem-solving among the student teams. By dividing the project into distinct modules, students are able to focus on key areas of expertise while also working collectively to integrate their solutions into a cohesive and functional drone system. In the following, we explore each of these submodules in detail to understand the tasks assigned to the students and the collaborative problem-solving skills they develop along the way:

(1) Autonomous Navigation Controller (ANC): Students are responsible for developing the flight control module of the drone, which involves hierarchical controller design and software implementation. The controllers stabilize the drone's attitude, altitude, and navigation along the QR trail. This submodule allows students to showcase their collaborative problem-solving skills in achieving stable and precise drone flight using software deployed on an embedded platform.

(2) Image Processing (IMP): In this submodule, students focus on the vision system of the drone. They utilize the camera feed to determine the drone's position based on the red line grid and detect and parse QR codes to identify the next flight target. Through this task, students have the opportunity to demonstrate their collaborative problem-solving abilities in developing the drone's vision capabilities using image processing techniques.

(3) Simultaneous Wireless Information and Power Transfer (SWIPT): Students tackle the implementation of hardware and embedded software for inductively transferring power from the drone's battery to a remote LED wall. They also leverage the power transfer link to transmit mission data and inductive link efficiency to an external LCD screen. This submodule emphasizes the students' collaborative problem-solving skills in developing efficient power transfer mechanisms and optimizing the communication between the drone and external devices.

(4) Communications (COMMS): Students develop a command center framework within the EAGLE drone to enable communication between different modules and a remote base station. They create a web Graphical User Interface (GUI) that displays crucial drone parameters, such as live video feed, drone coordinates, and telemetry data, and allows parameter upload capabilities. This submodule showcases the students' ability to collaboratively solve problems in optimizing wired and wireless routing and ensuring seamless communication within the drone system.

(5) Cryptography (CRYPT): In this submodule, students analyze the QR codes encountered along the drone's path. They authenticate the QR codes to ensure they are not malicious and decrypt them to obtain target coordinates. Students implement authenticated decryption algorithms in software and hardware, utilizing the FPGA on the Zybo board to accelerate real-time operations. This task highlights the students' collaborative problem-solving skills in ensuring data security and integrating cryptographic functionalities into the drone system.

2.2 EAGLE Timeline and Milestones

The EAGLE project comprises a well-structured timeline and milestone framework that not only enables students to develop the necessary technical skills but also emphasizes the cultivation of collaborative problem-solving abilities. Spanning across two semesters and consisting of a series of sessions (a total of 75 sessions, each lasting 2.5 hours), students engage in hands-on learning experiences to accomplish their EAGLE mission while honing their soft and technical skills.

The project timeline consists of four evaluation moments (T1-T4), shown in *Fig.* 2., each with corresponding milestones for each module. These milestones provide students with clear targets and foster their problem-solving abilities. After each evaluation, students receive extensive feedback, facilitating continuous improvement and learning.

[T0-T1]: The project begins with the **"Understand & Plan"** phase, emphasizing collaborative teamwork and effective communication. Students engage with their coaches (see next section) to comprehend the project's scope, allocate tasks, and establish well-defined interfaces. The team must also assign specific roles to each member to ensure effective collaboration throughout the project.

[T1-T2]: Moving into the **"Modeling"** phase, students work on their respective modules, aiming to achieve technical milestones demonstrated during demo and poster sessions. This phase encourages students to develop virtual component models and create initial versions of the project's modules, honing their problem-solving and modeling skills.

[T2-T3]: During the **"Component"** phase, students focus on module implementation, aiming for independent functionality by the second demo and poster session. Integration of modules begins, leading to a second set of milestones. This phase nurtures their ability to solve complex problems while collaborating on system integration.

[T3-T4]: The final **"Integration"** phase brings all modules together, gradually transforming the drone into an autonomous entity. This phase showcases students' problem-solving skills in integrating diverse components into a cohesive system. The project concludes with a final demonstration and presentation, further enhancing their collaborative problem-solving and communication abilities.

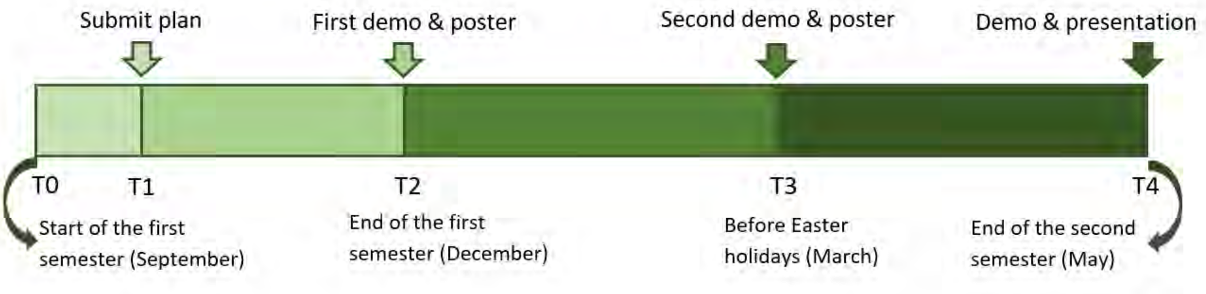

Fig. 2. EAGLE timeline and four evaluation moments

In addition to technical milestones, students are expected to develop and demonstrate soft skills throughout the project. Reporting on progress, reflecting on problem-solving approaches, and presenting technical solutions through various mediums (such as blogs, poster presentations, and live demos) foster effective communication, planning, and reporting skills essential for their future professional careers.

2.3 Teaching

The EAGLE project presents students with two distinct challenges that they must address simultaneously. Firstly, they are tasked with tackling a technically complex problem, requiring them to apply their knowledge and skills to overcome various technical challenges. Secondly, students must navigate the organizational complexities that arise from working in large groups, including effective teamwork, communication, and coordination. Moreover, the project emphasizes on fostering problem-solving capabilities within a collaborative team environment while also encouraging individual independence. By promoting both teamwork and individual autonomy, the EAGLE project aims to develop well-rounded and capable students.

To support students in their journey, the EAGLE project provides them with the autonomy to plan their work, manage their team, and establish effective communication tools. However, it is most likely that at certain stages of the project, students may require assistance or guidance. To ensure adequate support, the EAGLE students are accompanied by a dedicated team of professors and teaching assistants (TAs).

The support primarily refers to supporting each group of students collectively. The teaching staff meets with the group as a whole during the two designated days per week when students actively work on the project. These meetings serve as an opportunity to provide guidance, monitor progress, and address any group-level challenges or concerns. Additionally, the teaching staff recognizes the importance of individual support within each group. Students are encouraged to reach out to the teaching staff individually via email or through a dedicated program and web interface when they encounter specific problems or require personalized guidance. Furthermore, in the event of any issues or conflicts arising within a group, the teaching staff engages in one-on-one meetings with each member of the group. This approach allows for a more personalized and targeted resolution of problems, ensuring that the needs and concerns of each student are adequately addressed. The task division within the team of teaching staff is as follows:

Coaches: Two coaches, consisting of a Teaching Assistant (TA) and a supervisory professor, are designated to each EAGLE team of 10-12 students. The coaches are responsible for guiding and supporting the EAGLE team to foster effective teamwork and collaboration and emphasizing the development of soft skills across five key dimensions:

(1) Interpersonal Skills: Coaches assist team members in effective collaboration within a diverse, multi-disciplinary group.
(2) Problem Solving: Coaches encourage a balance between independent problem-solving and seeking help when needed, fostering creative techniques.
(3) Motivation: Coaches motivate teams to strive for higher goals and exhibit commitment towards their objectives.
(4) Project Planning: Coaches help teams devise comprehensive short-term and long-term plans, adapt and modify their plans based on their progress, ensuring timely and flexible adjustments.
(5) Project Management: Coaches emphasize regular meetings with structured agendas to synchronize progress, address challenges, and ensure well-organized project development.

Initially, the coaching approach is intensive, with active guidance and clear communication through in-person or online meetings. As the team progresses, the coaching transitions to a high-level supervision role, allowing the team to take on more responsibility for their work.

Overall, the coaches facilitate team growth by creating a collaborative environment and gradually empowering the students to work autonomously.

Technical experts: As already explained, the project is broken down into smaller modules, namely ANC, IMP, SWIPT, COMMS, and CRYPT. There are at least 2 technical experts for each of these modules. Their expertise helps students tackle complex technical challenges and ensures smooth progress throughout the project. Here are the key responsibilities and expectations for technical experts:

(1) Documentation Support: Technical experts are responsible for ensuring that students have access to proper documentation related to their respective modules. This includes providing relevant resources, reference materials, and technical guidelines to assist the teams in their work.
(2) Availability for Assistance: Technical experts are expected to be available to answer questions and provide guidance to the students. Promptly responding

to inquiries via email or other communication channels is essential in helping teams overcome technical issues they may encounter.

(3) Weekly Team Check-ins: Technical experts are required to check in with each team on a weekly basis. This allows them to monitor the teams' progress, provide feedback, and address any technical issues they may be facing. Regular engagement with the teams helps maintain a collaborative and supportive environment.

(4) Foster Effective Problem-Solving: Beyond technical skills, technical experts involve teaching students how to ask the right questions and directing them to the appropriate resources for finding answers. Encouraging creativity and innovative thinking while cautioning against unnecessary complexity helps the teams approach problem-solving in an efficient and effective manner.

Behind the scenes, the teaching staff meet regularly (at least bi-weekly) to discuss the progress of each team and address potential bottlenecks, such as hardware, software, and organizational issues. This collaborative effort allows the staff to provide guidance while empowering the students to take ownership of their work. To ensure the smooth knowledge transition to new Teaching Assistants (TAs), they receive training by shadowing senior TAs before assuming full responsibilities. Additionally, senior TAs organize a training day for the entire teaching staff prior to the start of the academic year. This training session focuses on tackling key project challenges, sharing valuable tips and tricks from previous experiences, and gaining a deeper understanding of potential issues students may encounter.

2.4 Feasibility and Scalability

The EAGLE project at KU Leuven is resource-intensive, with a team of 20 Teaching Assistants (TAs) and 9 professors supporting approximately 80 students. While the current resource allocation allows for effective guidance and support, it is important to consider the scalability of such a project in larger institutions with cohorts of over 300+ students. Given the limited resources, it is unlikely that the EAGLE project can be directly replicated on a larger scale. However, the project's framework and principles can be adapted and modified to suit the available resources and context of different institutions. It may be necessary to explore alternative approaches, such as smaller project teams or leveraging technology for remote coaching, to make project-based learning feasible and scalable in larger student cohorts.

2.5 Evaluation

The EAGLE project, being a part of the curriculum, incorporates a robust assessment framework that evaluates students' technical achievements, soft skills development, and material handling proficiency. The EAGLE guidance team conducts evaluations using a comprehensive rubric as shown in Table 1. for all assessment moments (T1-T4) throughout the year. Following each assessment, students receive detailed feedback on their team's performance, with subscores provided for technical achievement, teamwork, and planning and organization. The rubric categorizes team performance into different levels, ranging from failing to exceptional, for individual assessment criteria.

In addition, students are required to submit self- and peer-assessments for T2, T3, and T4, which contribute to the evaluation process. Peer evaluations carry increasing weight as the project progresses, and team members assess each other based on their contributions to the process and the product. Constructive comments accompany each assessment, fostering a constructive and fair evaluation environment. This comprehensive evaluation framework ensures a fair and thorough assessment of students' performance in the EAGLE project, encompassing technical achievements, soft skills development, and material handling proficiency.

Table 1. The EAGLE comprehensive evaluation rubric

EAGLE 1		Failing	Struggling	Sufficient	Advanced	Exceptional
	Milestones					
	Comments Milestones					
ANC	Milestone technical achievement (put a '1' in only one cell)					
IMP	Milestone technical achievement (put a '1' in only one cell)					
SWIPT	Milestone technical achievement (put a '1' in only one cell)					
COMMS	Milestone technical achievement (put a '1' in only one cell)					
CRYPT	Milestone technical achievement (put a '1' in only one cell)					
Team work	**Teamwork**					
	Comments teamwork					
	Discussion (GRADED BY COACH)					
	Independence and creativity (GRADED BY COACH)					
	Commitment (GRADED BY COACH)					
Plan & Org	**Planning and organisation**					
	Comments Planning and organisation					
	Submitted plan + system level diagram (SLD) + blog (GRADED BY INTEGRATION EXPERT + COACH)					
	Daily planning process during meetings (GRADED BY COACH)					
	Organisation (GRADED BY COACH)					

3 FINDINGS AND DISCUSSION

In this section, we present the findings from student feedback and discuss the effectiveness of the EAGLE project in terms of developing collaborative problem-solving (CPS) skills and other skills outlined in the introduction. The feedback was collected through a questionnaire answered by students who participated in the EAGLE project during the 2020-2021 and 2021-2022 academic years.

3.1 Student Feedback

The questionnaire included several questions aimed at understanding the students' perceptions and experiences in the EAGLE project. Here, we highlight the key findings (shown in *Fig. 3*. to *Fig. 7*.) from the questionnaire:

Importance and Added Value: One question asked students about the most significant added values of the EAGLE project. The responses showed that students highly valued the opportunity to work on an engineering challenge in a multidisciplinary subject. They pointed out the development of teamwork and problem-solving, as essential aspects of the project's value.

Workload Evaluation: Students were asked to evaluate the workload of the EAGLE project. The findings indicated that students perceived the workload as substantial. It is important to note that the foreseen workload for the project is 250 hours, based on the number of ECTS credits assigned to the course. This feedback helps put the workload into perspective and highlights the dedication and effort required from students to complete the project successfully.

Frequency of Evaluation Moments: The evaluation moments throughout the EAGLE project were also evaluated by the students. The feedback showed that the majority of students found the frequency of evaluation moments to be appropriate. This indicates that the scheduled evaluation sessions provided students with valuable opportunities to track their progress and receive feedback at regular intervals.

Clarity of Evaluation Criteria: Students' opinions regarding the clarity, transparency, and alignment of the evaluation criteria with the objectives of the project were gathered. While the majority of students found the evaluation criteria clear and transparent, some indicated that they were not always aligned with the project's objectives. This feedback provides valuable insights into areas where the evaluation criteria can be further refined to better align with the intended learning outcomes.

Mix of Team, Individual, and Peer Evaluation: The students' opinions on the mix of team, individual, and peer evaluations were also captured. The feedback indicated that students generally appreciated the combination of these evaluation methods. They recognized the importance of both individual accountability and collaborative team performance in the assessment process.

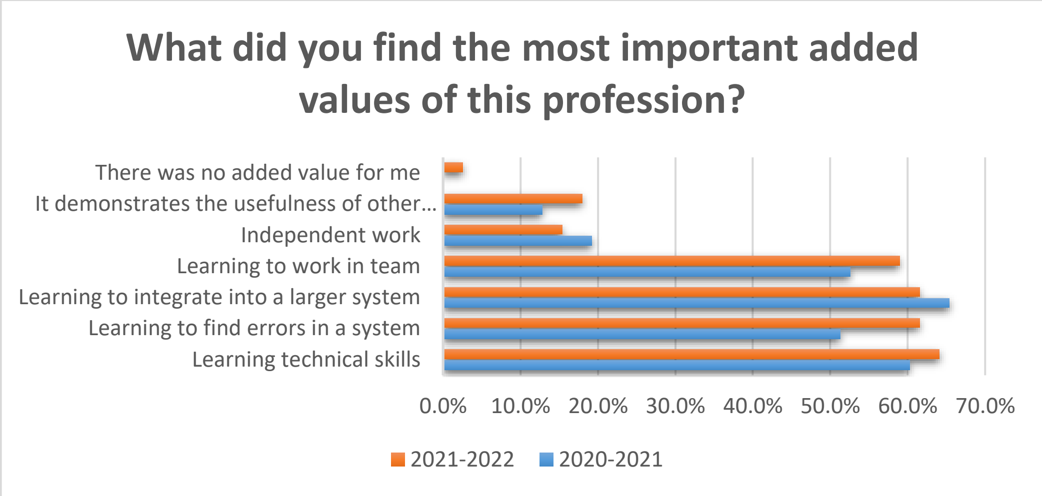

Fig. 3. Students' Perceptions of Added Values in the EAGLE Project

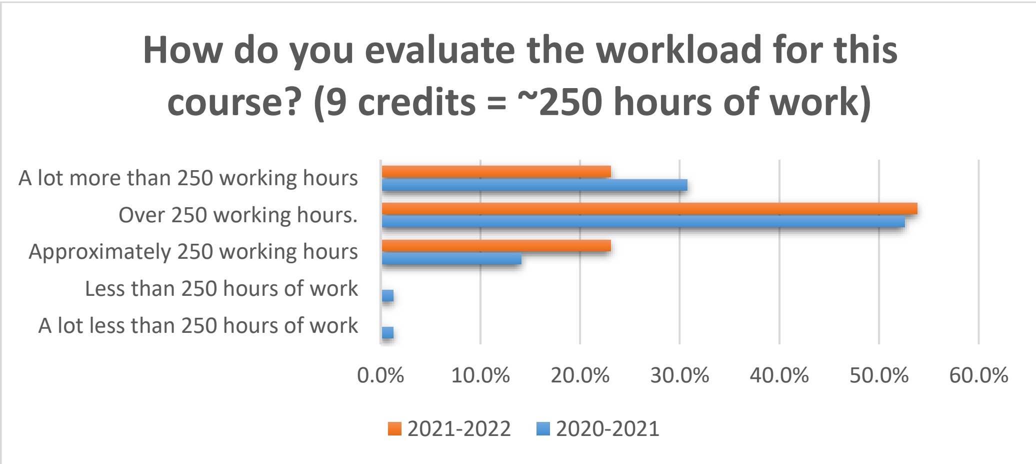

Fig. 4. Students' Evaluation of Workload in the EAGLE Project

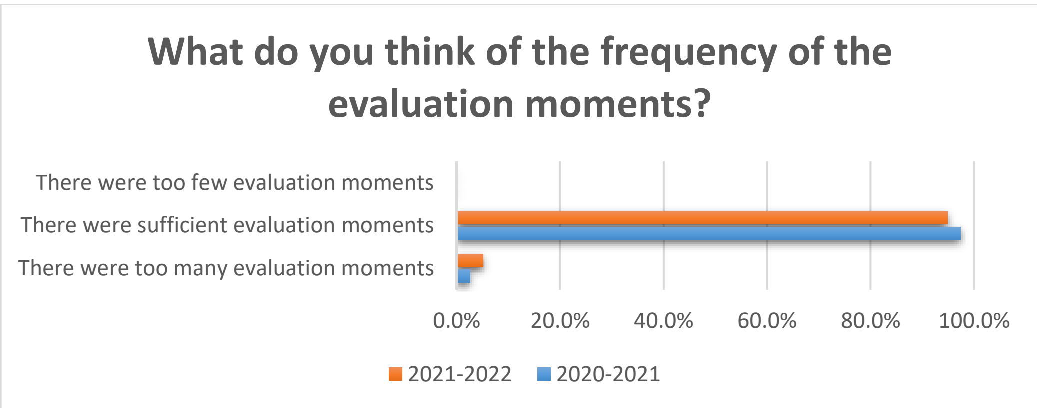

Fig. 5. Students' Feedback on Frequency of Evaluation Moments

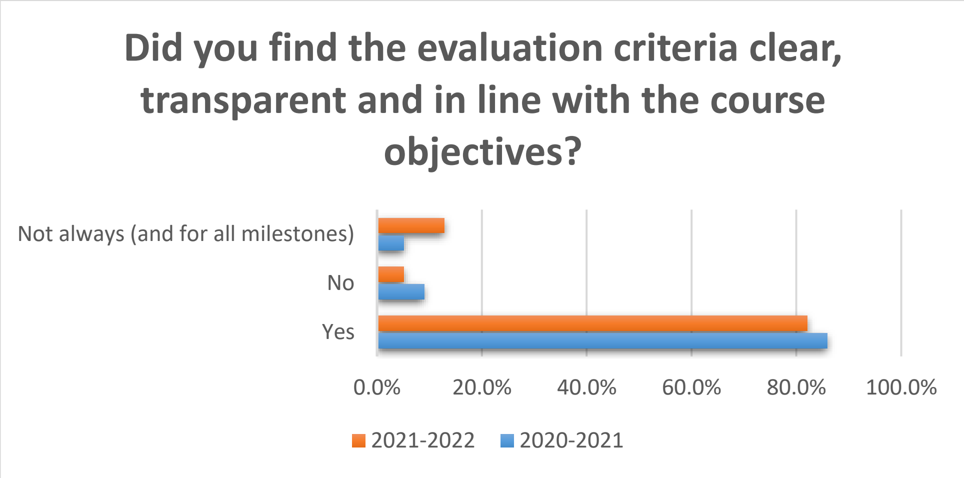

Fig. 6. Students' Views on Clarity of Evaluation Criteria

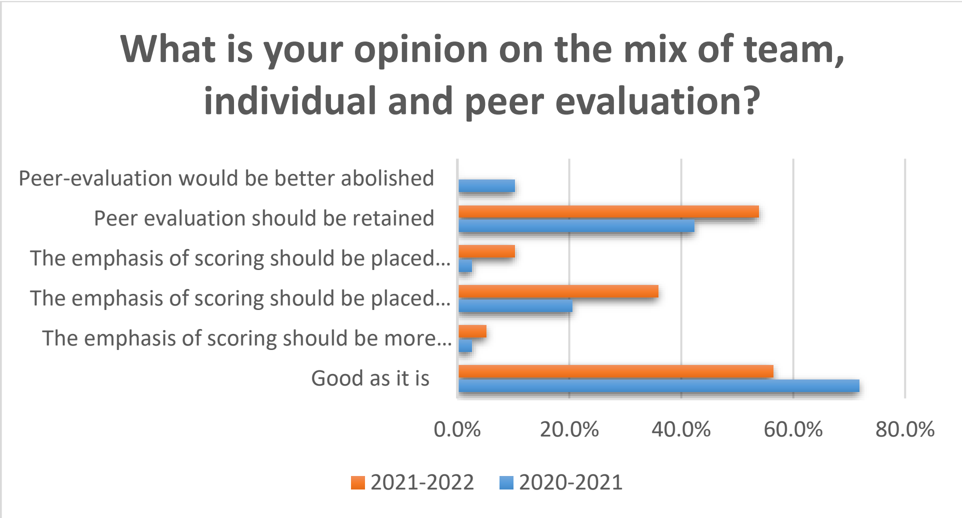

Fig. 7. Students' Opinion on the Mix of Evaluation Methods

3.2 Discussion and Implications

The findings from the student feedback provide valuable insights into the effectiveness of the EAGLE project and its impact on students' skill development. The positive feedback regarding the importance of teamwork, problem-solving, and negotiation skills aligns with the objectives of the project and supports the assertion that the EAGLE project effectively promotes collaborative problem-solving abilities.

Furthermore, the feedback regarding workload highlights the commitment and effort required from students to complete the project successfully. This information can be used to inform future iterations of the EAGLE project, ensuring that students are adequately prepared for the workload and can manage their time effectively.

The feedback on the evaluation moments, clarity of evaluation criteria, and the mix of evaluation methods offer valuable insights for improving the assessment process. By addressing students' concerns and refining the evaluation framework, the EAGLE project can continuously enhance the learning experience and provide more aligned assessment criteria.

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EXPLORING THE APPLICATION OF CHATGPT IN MECHANICAL ENGINEERING EDUCATION

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Conference Key Areas: *Education about and education with Artificial Intelligence, Innovative Teaching and Learning Methods.*
Keywords: *Artificial intelligence, ChatGPT, Education, Mechanical engineering.*

ABSTRACT

The use of language models such as ChatGPT in the field of engineering has gained popularity in recent years due to their ability to assist engineers in their projects and tasks. In this study, we evaluated the effectiveness of ChatGPT in supporting students' learning in the Mechanism and Machine Theory (MMT) subject. The study involved participants who were asked to interact with ChatGPT to obtain concept clarification and factual information related to MMT.

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Our results show that the majority of participants were familiar with ChatGPT and had used it for academic or technical questions. They also found it easy to use and felt that it covered a wide range of topics. However, they noted that the answers provided by ChatGPT were not always clear or were ambiguous.
Our research also emphasizes the significance of critical thinking, analytical skills, and decision-making abilities while utilizing ChatGPT. While ChatGPT can serve as a valuable aid to students, enhancing their productivity and providing them with prompt information, it cannot replace their expertise and specialized skills. More studies are required to delve deeper into the complete potential of ChatGPT in bolstering engineering education and practice.

1 INTRODUCTION

In the past decade, the integration of artificial intelligence (AI) in education has emerged as a growing trend. ChatGPT is a chatbot system that appeared in November 2022 based on the GPT-3 language model of artificial intelligence. It is currently based on the GPT-4 version of this language model.ChatGPT is developed by OpenAI, and it represents a significant advancement in the field of generative AI. This technology has the ability to generate highly coherent written content, which closely resembles human-created texts.

OpenAI, established in 2015, is a research laboratory that focuses on the development of AI products for the common good. With significant support from individuals and companies (Meany 2023), the laboratory has made rapid progress in the development of its AI technologies. OpenAI has released a number of machine learning products for the general public, with ChatGPT being among the most well-known.

Generative AI, which generates novel outputs based on training data, has become the poster child of a broader development in AI. ChatGPT is a prime example of generative AI, as it uses Natural Language Processing (NLP) to enable computers to engage in natural language conversations. This technology has significant implications for various industries, it is an emerging area for research, and there are opportunities for future research to establish the potential impacts of ChatGPT empirically (Dwivedi et al. 2023).

As AI technologies become more prevalent in education, it is crucial to understand their potential and limitations. The integration of ChatGPT into the educational process requires adaptations in pedagogical methods (Schäfer 2022). Nowadays, we have an additional tool available for both educators and students that must be used with responsibility. Rather than merely preventing plagiarism, the primary concern for educators is to foster critical engagement with the system (Craig 2023). Educators need to ensure that students use ChatGPT as a tool to supplement their learning and not as a substitute for their intellectual efforts (Lund et al. 2023).

While this technology is not yet equipped to solve targeted mechanical engineering issues, it can offer valuable support in certain tasks (Tara 2023; GPTPromptsHubTeam 2023). ChatGPT is a versatile language model and due to its capacity for producing lines of code in various programming languages, it holds particular potential for use in mechanical engineering contexts.

In this study, we showcase the potential of ChatGPT to enhance the teaching and learning of mechanical engineering by proposing a framework of academic activities structured in a four-level pyramid format, each building on the previous one, with increasing complexity of the academic activity. The first level, Knowledge Retrieval and Comprehension, focuses on basic concepts and understanding of mechanical engineering. The second level, Synthesis and Evaluation, is focused with the fusion and summarization of sources of information. The third level, Application and Analysis, deals with applying this knowledge to practical situations and analyzing results. Finally, the fourth level, Creation and Innovation, requires the application of the knowledge in novel ways to solve complex problems.

2 METHODOLOGY

The study involved 65 participants from the second year of the Bachelor in Industrial Technology Engineering at the Barcelona School of Industrial Engineering (ETSEIB), from Universitat Politècnica de Catalunya (UPC). The age range of the participants was between 20 to 22 years old.

To assess the participants' prior knowledge of ChatGPT, a questionnaire was developed consisting of 14 questions. The purpose of the questions was to gather information regarding the participants' level of acquaintance with ChatGPT, their prior use of the tool, and their opinions about its usefulness in college education. The questionnaire also included open-ended questions to gather more detailed information about the participants' experiences with ChatGPT.

Subsequently, a face-to-face session was designed to test the effectiveness of ChatGPT in supporting student learning using a four-level pyramid format. The session was held in a computer room and the students worked in pairs.The activities were structured in the following manner:

1) Knowledge Retrieval and Comprehension:
The participants were prompted to engage with ChatGPT to clarify concepts and obtain information related mechanisms and machine theory discussed in class. They were encouraged to ask questions related to the laws of physics, gear calculations and virtual power.

2) Synthesis and Evaluation:
Participants were tasked with using ChatGPT to summarize a specific section of the course textbook. Following this, they were instructed to generate five test questions related to Chapter 4 of the subject, each with four possible answer options (only one correct). After generating the questions, the students were required to seek the correct solution from ChatGPT. Finally, participants were asked to provide a critical evaluation of ChatGPT results.

3) Application and Analysis:
Participants were presented with a physical mechanical model to illustrate a curios behaviour of fundamental basis of mechanics. They were then asked to ask ChatGPT for help in understanding the fundamentals of the model.

4) Creation and Innovation:
The participants were instructed to use ChatGPT to generate novel ideas for mechanical engineering designs, products, and solutions based on the fundamental mechanisms discussed during the course. Specifically, they were prompted to consider ways to input their own models into ChatGPT. This activity aimed to test the participants' ability to apply their knowledge and creativity to practical engineering scenarios, as well as to evaluate the potential of ChatGPT as a tool for ideation and design in mechanical engineering.

In the face-to-face session, information was collected, also through a form, on the perception of usefulness of the ChatGPT that the students had for the different tasks proposed.

3 RESULTS

3.1 Usage and Perception of ChatGPT

All the students were familiar with ChatGPT. Among them, 70,8 % reported having used it, while 29,2 % knew about it but had not yet tried it. Out of the total surveyed students, those who had previously used the tool (46 out of 65) were the ones who continued with the questions about ChatGPT usage. Therefore, the following percentages were calculated based on this group. Among them, 39,1 % reported using it on a weekly basis, 34,8% used it between 5 and 15 times, and 26,1 % used it less than 5 times.

Students primarily used ChatGPT for academic questions (95,7 %) or technical questions (56,5 %). Fewer students used the tool for personal questions (10,9 %) or entertainment (37 %).

In terms of the usefulness of ChatGPT, 52,2 % of the students indicated that they consistently or frequently found the answers provided by the tool useful, while 34,8 % reported that they were only useful on certain occasions, and 13 % found them rarely useful. The majority of the students found ChatGPT to be user-friendly (82,6%) and indicated that it covers a wide variety of topics (78,3 %). However, they also highlighted that the answers provided were not always clear (76,1 %).

In general, most students agreed that ChatGPT was a valuable resource for university students, with 65,2 % indicating that it was useful for specific topics and 34,8 % finding it highly useful. Additionally, the survey indicated that a significant majority of students (84,8 %) believe that ChatGPT can serve as a viable alternative to traditional research sources such as libraries and academic databases. Moreover, the majority of students (81,3 %) do not believe that ChatGPT can replace MMT classes (see Fig. 1).

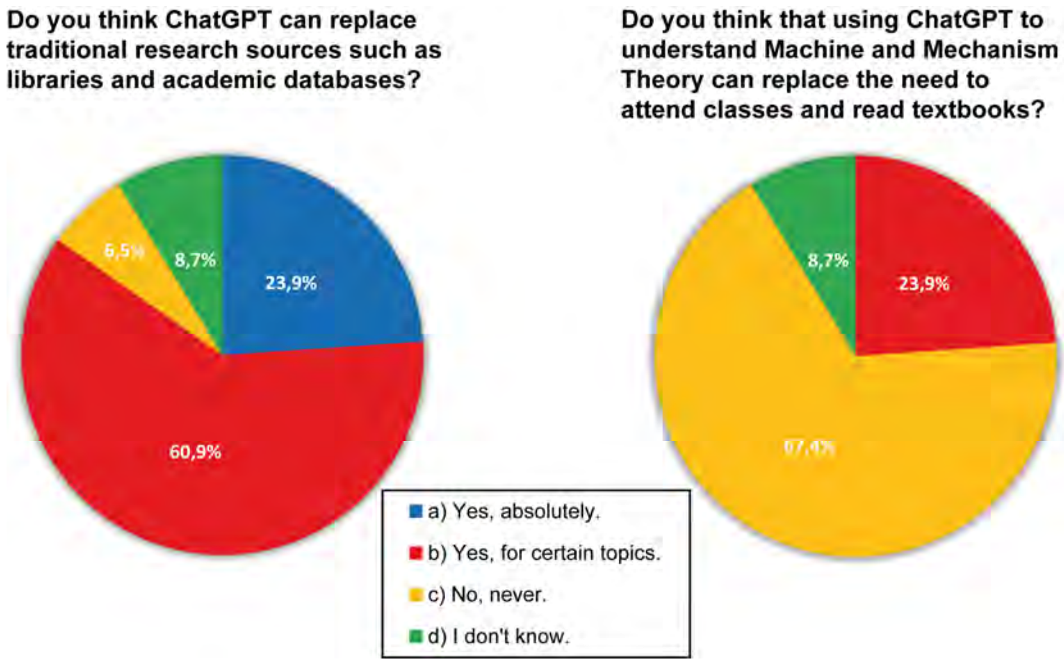


Fig. 1. Two questions about using ChatGPT at the university

Continuing with the questions about mechanism and machine theory, when specifically asked about the application of ChatGPT to the MMT subject, on one hand all students unanimously agreed that it could be useful for theoretical concepts, but on the other hand, less than 25 % of the students believed that it could be useful for solving exam problems, especially those involving geometric equations (see Fig. 2).

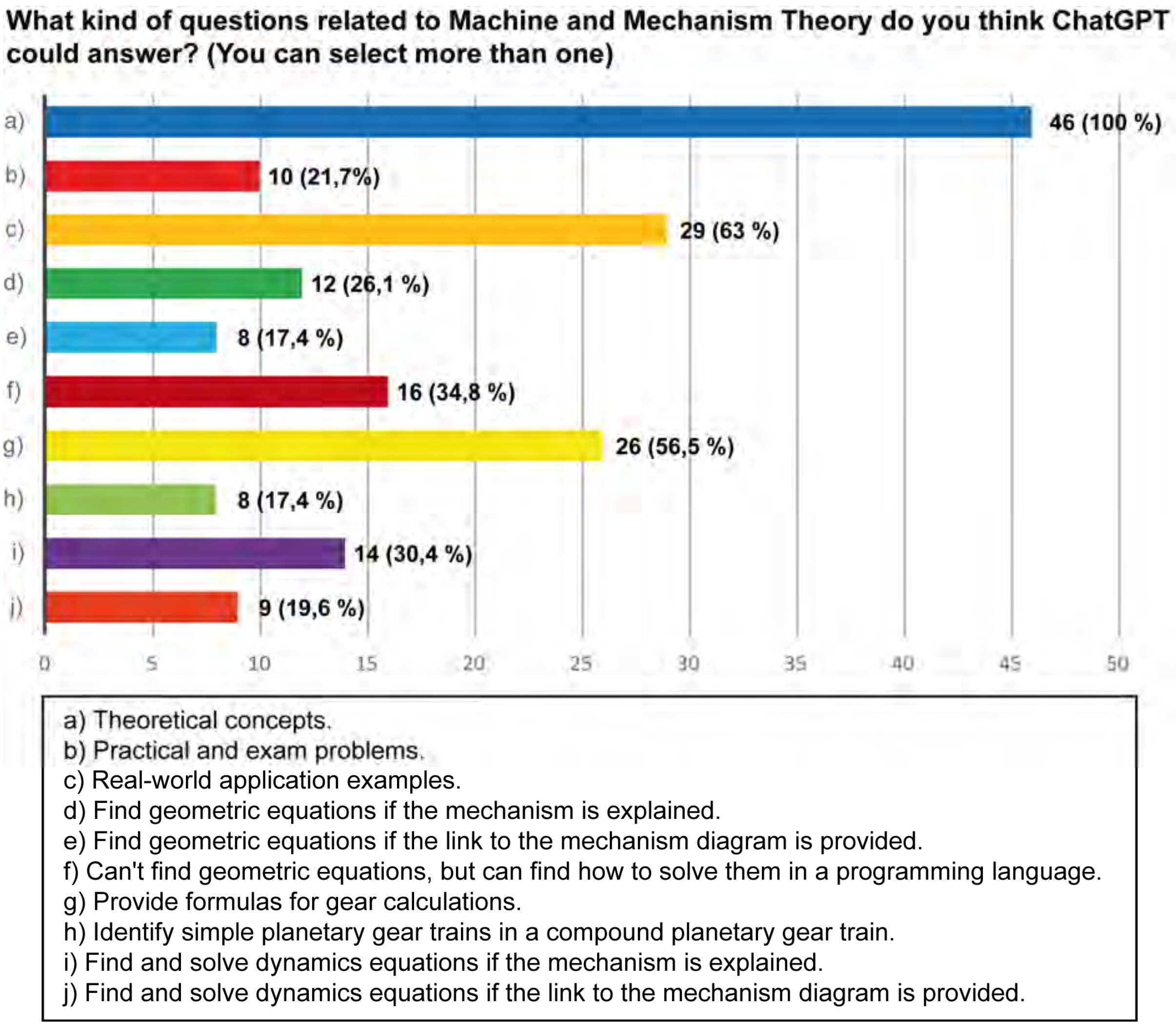


Fig. 2: Perception of the usefulness of ChatGPT in the MMT subject

In the open-ended questions, students mentioned that ChatGPT could help them with theoretical questions such as friction cone, holonomy, redundancies, or degrees of freedom concepts. Some students also suggested that ChatGPT could be useful for solving exercises, but others noted that its contribution is currently limited since it cannot interpret diagrams or schematics.

3.2 Feasibility of ChatGPT in Mechanism and Machine Theory

ChatGPT was evaluated based on its performance in the defined levels of tasks related to mechanical engineering, specifically in mechanism and machine theory. In the first level (Knowledge Retrieval and Comprehension), ChatGPT was found to be a reliable tool for obtaining definitions, particularly for concepts such as gears, degrees of freedom, kinematic pairs, Grashof's law, holonomy, inversions, etc.

Both, authors and students noted that ChatGPT's responses often contain inaccuracies, and that the accuracy of its responses varies depending on the language used, with less accurate results observed in Catalan and Spanish compared to English. Therefore, critical thinking skills are crucial when using ChatGPT to ensure that the information provided is reliable and appropriate. Analytical skills and decision-making abilities are also essential to evaluate the responses generated by ChatGPT and use them effectively.

For text summarization tasks (second level), ChatGPT performed reasonably well although it struggled with texts containing equations or a high number of variables. Other AI tools like Humata.ai may be more suitable for summarizing such texts.

ChatGPT's performance in the third and fourth levels of the pyramid tasks was found to be limited. In terms of application (level 3), it was capable of correctly solving some reasoning tasks that involved the application of simple formulas, but it made mistakes when dealing with more complex equations and variables. Therefore, students must not rely solely on ChatGPT's responses and use their critical thinking skills to verify the accuracy of the tool's output. Furthermore, it is worth noting that different users may receive varying and inconsistent responses to the same prompt from ChatGPT, as depicted in Fig. 3. It is important to highlight that in some cases, ChatGPT was unable to correctly solve the equation involving combined operations.

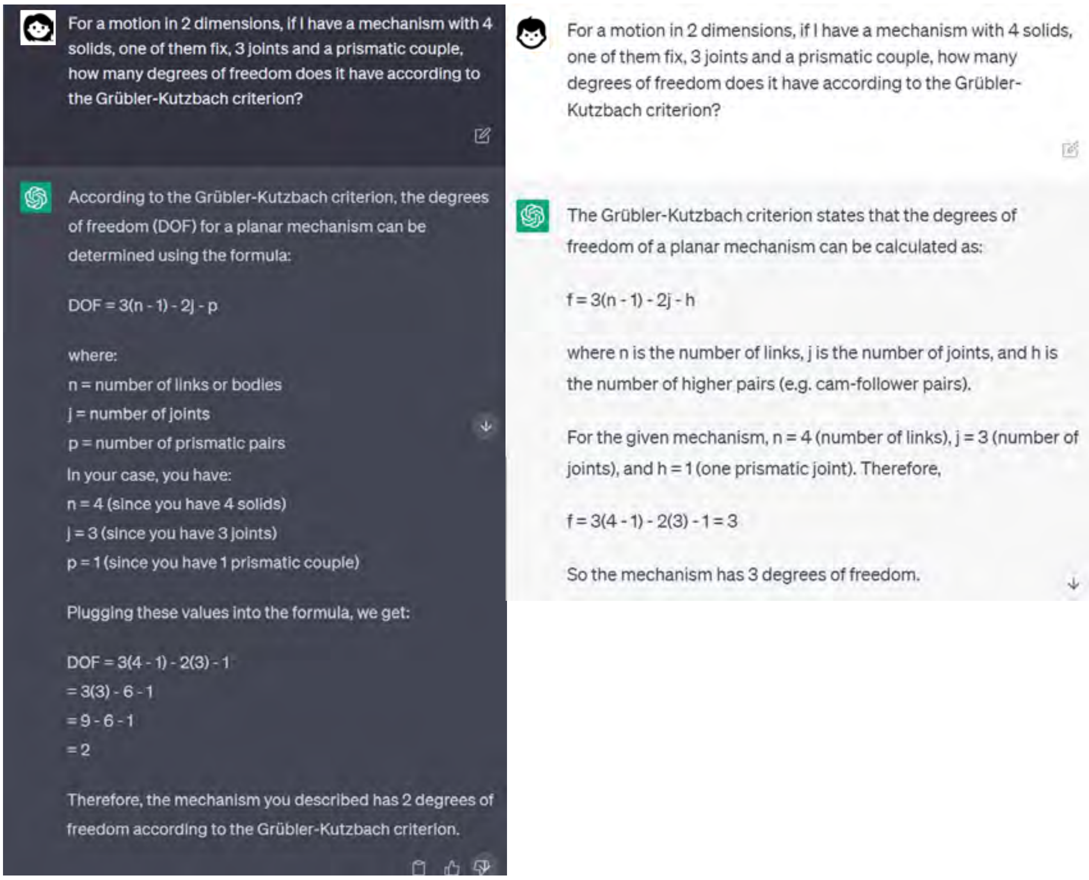
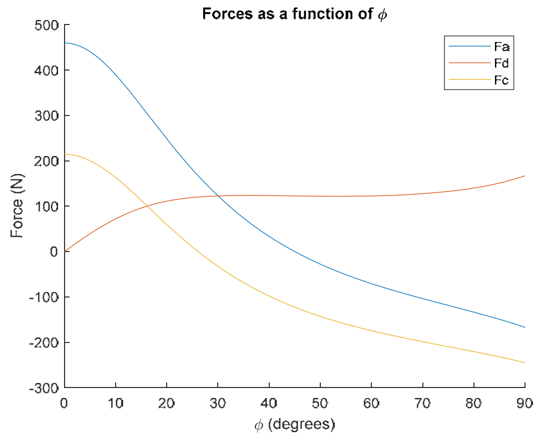


Fig. 3: Same prompt and two different answers

It is worth noting that ChatGPT has the ability to generate computer code for tasks such as solving geometric equations, regardless of the programming language used (including Python, Matlab, R, C++, Fortran, etc.). When prompted appropriately (with occasional need for interaction when error messages arise), ChatGPT can produce the proper code (see Fig. 4). This functionality, since coding is not a required competency in MMT subject, has the potential to greatly aid students and can be seen as a valuable tool for them.



(a) (b)

Fig. 4: (a) ChatGPT prompt requesting a Matlab code to solve a system of equations (b) Correct result obtained in Matlab with the provided code

As a language model, ChatGPT has limitations when it comes to creating mechanical designs from scratch. However, it can provide some useful ideas and suggestions to assist mechanical engineers in their design process. When prompted with specific design requirements, ChatGPT can generate potential solutions that students may not have considered before.

While ChatGPT may not be able to create complete designs on its own, its potential in this field is continually increasing. The authors of the study noted that ChatGPT was previously unable to provide any schema for mechanical designs just a few months ago. At the time of conducting this study, ChatGPT demonstrated the ability to generate drawings of mechanisms using textual characters (see Fig. 5). However, the quality of the drawings was poor and often difficult to comprehend. As the tool continues to improve, it has the potential to become an even more valuable asset for mechanical engineers looking to streamline their design process and explore new avenues for innovation

Fig. 5: Prompt and chatGPT answer for a schema of a four bar mechanism

4 SUMMARY AND ACKNOWLEDGMENTS

To summarize, this paper discusses the reliability and limitations of ChatGPT as a tool for mechanical engineering students. Our findings reveal that university students primarily use ChatGPT for academic and technical questions, and they find the tool easy to use and capable of covering a wide range of topics.

Applying this tool to mechanism and machine theory field, we want to highlight its accuracy in obtaining definitions and reasonable performance in text summarization, but limitations in handling complex equations and creating designs.

Although ChatGPT holds potential to support engineering student tasks, it is vital to approach its responses with critical thinking and acknowledge its limitations. Further research is required to develop advanced Natural Language Processing models for engineering tasks. As teaching, learning, and academic research undergo transformative impacts, it is important to remain open-minded about the potential applications of these technologies.

We think that ChatGPT should be seen as an assistant that can increase students' efficiency in completing tasks and projects. As such, it is recommended that engineering curricula incorporate the use of language models like ChatGPT to prepare students for the future of engineering and to enhance their problem-solving abilities.

The authors would like to thank the students who participated in the study. Additionally, we thank the developers of ChatGPT for providing us access to their technology. This paper has been developed with the assistance of ChatGPT,

highlighting the collaborative role of AI technologies and human skills in scientific research.

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An Innovative Approach by ENTER Network: Integrating Sustainable Development into Professional Training for Engineering Educators

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Conference Key Areas: *Please select two Conference Key Areas*
Keywords: *Please select one to five keywords*

ABSTRACT

This paper discusses the development of a new pedagogical training program for engineering educators, created by the ENTER Network and co-funded by the EU. The program consists of modules that include courses designed to develop specific competencies. The selection of courses and competencies was based on surveys conducted with various stakeholders, including engineering educators, HEI administration, HEI engineering students, potential employers of HEI engineering graduates, and representatives of governmental bodies involved in education. The paper focuses on the relevance and origin of competencies addressed in the Sustainable Development Course, and presents the syllabus for this course, including information on its objectives, content, teaching materials, structure, and assessment procedures.

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1 INTRODUCTION

The prevailing complexities of the 21st century necessitate an intersection of various disciplines to address the challenges that our world currently faces. Engineering, a crucial player in societal development, has a significant role in navigating these issues. Notably, the United Nations Sustainable Development Goals (SDGs), agreed upon by 193 member states in 2015, encompass several engineering-related targets that aim to better the quality of life for humanity. To this end, the need to align engineering education with the principles of sustainable development is paramount.
The rationale for integrating sustainable development in engineering training is manifold. Primarily, the engineering profession directly influences human health, safety, and overall wellbeing. As such, engineering educators bear a significant responsibility to ensure that their teachings are aligned with SDGs. Traditional education often falls short in this regard as it provides limited opportunities for educators to explore and solve real-world problems. Hence, the necessity to incorporate sustainable development principles into engineering education becomes evident.
The ENTER Network's pedagogical training programs for engineering educators is an innovative approach to integrating sustainable development principles into engineering education. Embarking on a mission to revamp professional development programs for engineering educators, the ENTER Network developed a comprehensive, multi-level modular system. The programs, grounded in international cooperation and available in various formats, were designed to cater to the evolving needs of educators in this field.
To tailor the programs effectively, a broad survey was conducted across several countries to identify essential competences. Stakeholders ranging from engineering educators, higher education institutions' administration, students, employers, to government educational bodies were involved, ensuring a comprehensive perspective on the competences required for advanced engineering pedagogy

2 SELECTION OF COMPETENCES FOR THE PROFESSIONAL DEVELOPMENT PROGRAM

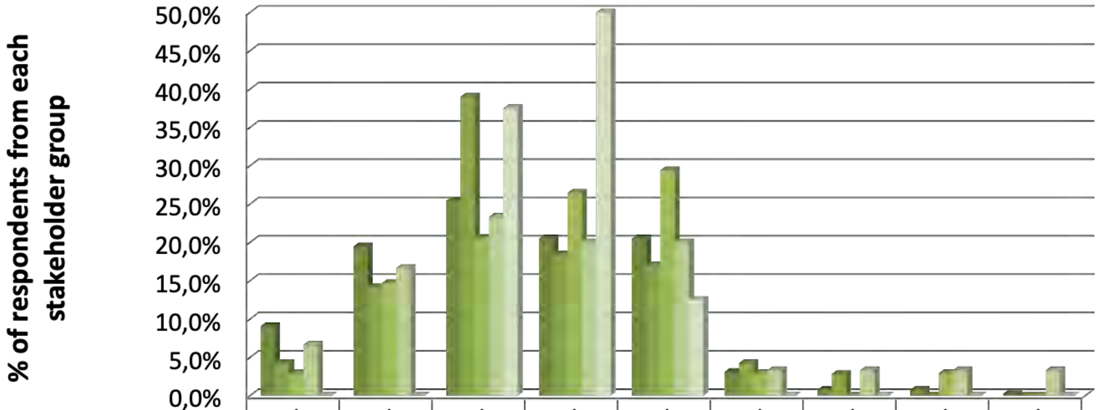
Under the ENTER Project, a major aim was to identifying the competences to be addressed in professional development programs for engineering educators. These programs were conceived as multi-level modular system for pedagogical training of engineering educators based on an international network cooperation, offered in different formats: onsite, online, and blended learning.

A broad survey was implemented in several countries to identify essential competences for these programs, as suggested by various stakeholders. The stakeholders' importance value, the proportion of universal and professional competences, and the final rating of competences and courses were key areas of discussion. The final examine survey resultsed on competences proposed by different stakeholders. Five stakeholder groups were identified:
- Engineering Educators/Faculty members,
- Higher Education Institutions (HEI) administration,
- Engineering students,
- Employers,
- Representatives of governmental educational bodies.

The survey result for the five groups of stakeholders was: 497 out of 600 Engineering Educators/Faculty members, 163 out of 200 from HEI's administration, 56 out of 60 Engineering students, 75 out of 100 Employers, and 22 out of 40 Representatives of governmental educational bodies, totaling to 813 out of a possible 1000 respondents.

2.1 Survey Results

The survey provided valuable insights into the proportion of interpersonal competences (IC) and professional competences (PC) required for advanced training programs. The summary of this survey weighting IC/PC is depicted in figure 1.



	10/90	20/80	30/70	40/60	50/50	60/40	70/30	80/20	90/10
Engineering Educators	9,1%	19,5%	25,5%	20,5%	20,5%	3,1%	0,8%	0,8%	0,3%
HEI administration	4,3%	14,2%	39,0%	18,4%	17,0%	4,3%	2,8%	0,0%	0,0%
Employers	2,9%	14,7%	20,6%	26,5%	29,4%	2,9%	0,0%	2,9%	0,0%
Students	6,7%	16,7%	23,3%	20,0%	20,0%	3,3%	3,3%	3,3%	3,3%
Government reps	0,0%	0,0%	37,5%	50,0%	12,5%	0,0%	0,0%	0,0%	0,0%

Fig. 1. The interpersonal competences (IC) and professional competences (PC) ratio for advanced training programs (% IC / % PC)

Interestingly, four competences were eliminated from the final rating. These included specific knowledge areas in pedagogy and engineering, the ability to represent one's professional group, and a deep understanding of the teaching course area and teaching methods. The remaining competences were mapped to the proposed professional development program courses.

2.2 Competence Rating

Participants were asked to assess the importance value of each stakeholder group. This process led to a unit weight of stakeholder's importance, which was critical in determining the final rating of competences and courses.
Based on the survey results and stakeholder importance, a final rating of competences (top 14) was produced. Considering these competences, courses were created and divided into 3 modules of Professional Development Programs..
The competences considered relevant by the stakeholders were the following 14 competences:
1 - Innovations in engineering pedagogy.

Ability to choose optimal strategies and teaching methods using traditional and innovative means, taking into account technosphere development paths, trends and challenges in engineering education

2 - Time management

Ability to manage time efficiently and prioritize professional activities

3 – Effective interaction

Ability to effectively interact with audience and increase students' interest in the discipline, using psychological tools and multimedia technologies

4 - Enhancement of learning interactivity

Ability to develop, adapt and implement modern interactive teaching and learning methods and technologies (inter alia, aimed at increasing students' motivation)

5 - Systems analysis in education

Ability to apply system approach to solving problems of Engineering education

6 - Pedagogical psychology and communication

Ability to apply psychological and pedagogical technologies to professional activities of a teacher

7 - Interaction with stakeholders

Ability to work efficiently with the results of scientific research to ensure their publication, to cooperate with labor market and other stakeholders

8 - Sustainable development

Ability to apply the principles of Sustainable development in the global context

9 - Digital education

Ability to design, organize and accompany educational process in X-learning environment

10 - Problem-based, project-based and Practice oriented learning

Ability to form students' experience of individual and team work on solving real engineering problems and developing of new engineering solutions

11 - Learning outcomes' assessment

Ability to design forms and methods of continuous monitoring, feedback and final assessment of education quality

12 - Course design

Ability to develop teaching materials that foster students' competences formation

13- Engineering innovation process

Ability to lead research, innovative and design activities (work) of students and student teams, and to foster students to generate innovative ideas, to operate their development and implementation stages.

14 – Lifelong learning

Ability to "ongoing, voluntary, and self-motivated" pursuit of knowledge for either personal or professional reasons, enhancing social inclusion, active citizenship, and personal development, as well

The insights gained from this analisys are considered instrumental in shaping the future of engineering pedagogy, thus equipping the next generation of engineers with the skills and competences they need to succeed in their profession.

3 SUSTAINABLE DEVELOPMENT COURSE: DESIGN AND DEVELOPMENT

The Sustainable Development course, a key component of the program, seeks to improve and develop the knowledge, understanding, skills, and abilities of engineering educators to teach students to recognize that engineers operates in a broad societal context and to take that context into account in their professional activity. The main aim of the course is to develop strategy to incorporate sustainable development principles into engineering education at large, including specific engineering courses.

3.1 Course Aims and Structure

The course aims to instill sustainable development (SD) mindsets on both professional and personal levels. It promotes critical thinking, holistic systems thinking, entrepreneurial thinking, global mindset, cultural agility, and valuing learning over knowing[^2^]. These qualities are unique to humans and cannot be replicated by machines, highlighting their importance in the education of future engineers.
The course also seeks to design learning for human needs. In the 21st century, higher education must shift the learners' perception that learning is not just about the acquisition of knowledge and skills, but also about developing human qualities and dispositions to cope with an uncertain world[^3^]. As such, the course is designed to focus on gaining skills to learn and relearn, and to change perspectives. It implies that the current faculty-centred curricula (anchored by existing physical spaces, staff resources, time-bound schedules) have to be transformed into (more) learner-centred and meaningful curricula with freedom of choice for the students.
Importantly, the course also aims to nurture a culture of experimentation and innovation, promote impact-focused education, develop the necessity of analysis through the prism of a green society, integrate scientific and professional integrity in the curricula, strengthen university-industry collaboration, and empower students to foster leadership and ethical behavior[^4^].

3.2 Methodology

The approach taken in the creation of the Sustainable Development Course began with the identification of key competencies required for effective teaching of sustainable development principles in engineering education.
The ENTER Network applied an innovative approach to the development of the training program, utilizing a blend of traditional and modern pedagogical techniques, such as Problem-Based Learning (PBL), Forum Theater, Jigsaw, Team-work, and Case study. This methodological approach was designed to promote active learning, critical thinking, and creativity, essential skills for engineering educators seeking to incorporate sustainability into their teaching (Thomas et al., 2019).
The course syllabus was structured to provide a comprehensive overview of the concepts and practices of sustainable development, with a specific focus on their application to engineering education.

3.3 Course Description

The Sustainable Development Course, as part of the IPET 2 Program, is a compulsory course offering a total contact time of 20 hours, divided between lectures, tutorials, and practical or project work. The course is designed to foster the development of sustainable development (SD) mindsets on both a professional and personal level, and the design of learning experiences that meet human needs. The course also emphasizes impact-focused education, the importance of green society analysis, the culture of experimentation and innovation, the integration of scientific

and professional integrity in the curricula, university-industry collaboration, and the empowerment of students to foster leadership and ethical behavior.
The course content is distributed as follows: an Introduction to Sustainable Development, comprising 10% of the course; Engineering Curriculum and Education for Sustainable Development, comprising 20%; Pedagogical Strategies for Learning Sustainability in Engineering Education, comprising 30%; SDG Challenge as the capstone project, comprising 25%; and Extracurricular Activities to Foster SD Ethos, comprising 15%.
The teaching materials for the course include a variety of sources such as handbooks, resource guides, journal articles, and technical reports. The main teaching materials are provided by Mulder (2006), Leal Filho and Nesbit (2017), Sivapalan, Clifford, and Speight (2016), and WFEO (2015), with complementary teaching materials sourced from Graham (2018), Grasso and Burkins (2010), Henderikx and Jansen (2018), Kamp (2016), and UN (2015).

3.4 Course Learning Outcomes

Upon successful completion of the Sustainable Development Course, in conformity with EUR-ACE accreditation criteria, the students should be able to demonstrate the following learning outcomes as shown in Table 1.

Table 1. Sustainable Development Course Learning Outcomes

Group of outcomes	**Outcome (number & name)**
Knowledge and Understanding	LO1 - Nurture mindsets and meanings in curricula; LO2 - Develop agile curricula with flexibility and freedom of choice for the students;
Engineering Analysis	LO3 - Develop the necessity of the analysis through the prism of green technologies;
Engineering Design	LO4 - Promote impact-focused education through interdisciplinary student-centred projects with societal relevance (where societal relevance is the centre of engineering).
Investigations	LO5 - Nurture a culture of experimentation and innovation in education on a limited scale, within a strategy for implementing more widely successful innovations;
Engineering Practice	LO6 - Integrate scientific and professional integrity and business ethics in engineering curricula; LO7 - Intensify the collaboration with industrial partners and create more opportunities for engineering practitioners in the classroom, engineering projects and internships at companies;
Transferable Skills	LO8 - Empower students (intra- and extracurricular) to foster leadership, ethical behaviour, deep collaboration, interdisciplinarity and creativity.

3.5 Assessment Procedures

The assessment for the course involves an initial self-assessment, designed to diagnose the SD ethos of enrolled educators. This does not impact the course evaluation but serves to inform educators of their starting point. The main form of assessment is through the creation of a portfolio, which engineering educators compile over the course of the professional development program elaborating their own strategy in integrating SD in a real course (given by them at their higher education institutions) in order to demonstrate the acquired skills and knowledge to ensure SD ethos among engineering educators.
The final assessment involves submission of portfolio itself, oral presentation and discussion.

The portfolio's evaluation is rooted in the quality and breadth of reflection on the course's material and concepts, the application of learned skills and knowledge, and the ability to integrate and synthesize different concepts. This is executed through a four-part rubric: a checklist ensuring all necessary components are included (25%), an assessment of whether the work is correctly executed (mechanics) (25%), an evaluation of the work's completeness (information) (25%), and an appraisal of the work's comprehensive nature (depth) (25%). Each area is rated on a scale from 1 to 5, where 1 signifies "not at all", 2 denotes "somewhat", 3 indicates "mostly", 4 represents "entirely", and 5 equates to "above expectations".

4 SUSTAINABLE DEVELOPMENT COURSE IMPLEMENTATION

The Sustainable Development Course, part of the iPET program, was introduced in 2021 across six higher education institutions that are members of the ENTER Project consortium. Given the Covid-19 restrictions, the course was primarily offered online or in a blended format. This course attracted a total of 186 teachers from various engineering disciplines, all of whom were required to integrate sustainable development principles into their courses at their respective universities. This involved the development of unique teaching strategies and adjustments at the micro-curricular and, in some instances, program levels.

To assure the quality of the course, the enrolled students were asked to complete a short questionnaire, aimed at gathering feedback regarding their satisfaction levels and aspects of the course that could be improved.

In response to the question, "What did you like most about the course?", several themes emerged. Participants enjoyed the balanced module layout and the opportunity to learn new teaching methods aimed at achieving Sustainable Development Goals. The relevance of the information on sustainable development within engineering education was also appreciated. Moreover, participants noted the value of involving all trainees in the learning process, particularly through practical tasks. The team-based practical exercises were a particular highlight, allowing for an interesting mix of people from different universities, including international colleagues. Lastly, participants praised the course for providing new and useful information and facilitating an exchange of experiences and perspectives on teaching engineering disciplines.

As for the question, "What aspects of the course could be improved?", suggestions were made to supplement the course with video materials and e-courses, and to expand the possibilities for individual consultation. Some participants suggested reconsidering the scheduling of zoom-classes, as balancing these with job responsibilities was occasionally challenging. Finally, feedback indicated that the amount of project-based activities could be reduced.

5 CONCLUSIONS

The ENTER Network has successfully identified competences for professional development of engineering educators through a broad survey across multiple stakeholder groups. The resulting pedagogical program, comprising onsite, online, and blended learning, is modular and adaptable to various teaching styles. The survey analysis revealed a distinct ratio of interpersonal and professional competences required, with 14 key competences being identified as essential. An innovative course on Sustainable Development was developed, with a focus on fostering human-centric, impact-focused education, promoting a culture of experimentation, and encouraging lifelong learning. The course assessment method encourages educators to integrate sustainability principles into their teaching practices. Future improvements could include the addition of video materials, e-courses, and individual consultation sessions. The feedback from the first runs of the course was generally positive, with some minor suggestions for improvements.

As the field of sustainable development is rapidly evolving, the Sustainable Development course, as part of the professional development program for engineering educators, should be dynamically revised to stay current. This involves continuous monitoring of emerging trends, challenges, and innovations in the field, and integrating this knowledge into the course curriculum. This would ensure that the course remains relevant, comprehensive, and effective in equipping engineering educators with the skills and knowledge they need to educate the next generation of engineers to address the sustainability challenges of the future. Additionally, feedback from educators and students should be regularly solicited and used to improve and refine the course. Regular updates and revisions will ensure that the course continues to meet its aims and remains at the forefront of sustainable development education.

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ENGAGEMENT and SOLIDARITY WHILE LEARNING

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ABSTRACT
2020 and 2021 were difficult years for students attending higher education and secondary education especially if they were preparing to enter higher education. Teaching was adapted, and assessments were the possible ones according to what we lived and experienced. Thus, students need innovative and stimulating teaching and learning practices that motivate and involve them in the teaching/learning processes. Information and Communication Technologies (ICT) and digital platforms have seen their indiscriminate use, not without sometimes, teachers and students questioning whether they were being used in the best conceivable way or taken full advantage of. Face-to-face group work and involvement with the needs of colleagues lost some space for achievement and effectiveness. The preference for individual work and the visible reduction in solidarity among colleagues was an issue/question posed at the beginning of this study. An activity was proposed over a semester to students of Statistical Methods from Informatics Engineering. This curricular unit enrols 533 students, 85 on an after-work basis. The objective of this proposal was to create a collaborative learning platform where students could interact with each other within the scope of the curricular unit. Cumulatively, it was an objective that students deepen the topics taught in class, including references provided, and reviewing exercises conducted by their colleagues. Regularly professors corrected the materials proposed by the students. All students who participated had access to all the work developed. The evaluation of students' involvement, collaboration, and solidarity in addition to the results will be discussed and presented.

1 INTRODUCTION

1.1 Activity Contextualization

The process of learning Mathematics in Engineering courses is the target of varied and deep studies and research by the teachers who teach and develop it (Babo, L. et al., 2023 [1]). The pandemic caused widespread disruption to educational systems, with schools and universities around the world having to rapidly transition to remote learning to comply with social distancing guidelines and reduce the spread of the virus. This sudden shift to online learning posed significant challenges for both students and educators, as they had to adapt to innovative technologies and modes of instruction while dealing with the social and emotional stresses of the pandemic. For students preparing to enter higher education, the pandemic created additional challenges. College and university campuses were also closed or operating at reduced capacity, which limited opportunities for campus visits and extracurricular activities that allow students to engage on group studying contents and socializing. The pandemic also had significant economic impacts, with many families facing job losses or financial strain, which could affect their ability to afford higher education. Overall, the pandemic created a difficult and uncertain environment for students, particularly those preparing for higher education, and required them to be resilient and adapt to significant changes in their learning environments and plans. Teaching was adapted, and assessments were the possible ones according to what we lived and experienced. Thus, students need innovative and stimulating teaching and learning practices that motivate and involve them in the teaching/learning processes (Viberg, Olga, 2023 [5]). Information and communication technologies (ICT) and digital platforms have seen their indiscriminate use, not without sometimes, teachers and students questioning whether they were being used in the best feasible way or taken full advantage of. Face-to-face group work and involvement with the needs of colleagues lost some space for achievement and effectiveness. The preference for individual work and the visible reduction in solidarity among colleagues was an issue/question posed at the beginning of this study. Within this education scenario, the authors looked for a solution that could engage their students and provide help between them. Due to all developments induced using digital platforms during pandemic times, we were looking for a platform where students initiative, interaction and visualisation was easy to achieve. According to several authors (e.g., Fisher, C. D., 2017, [2], Mehta K. J., Miletich I., & Detyna M., 2021, [3] and QiaoZhi, MuSu, 2015, [4]), « *Padlet is an excellent online collaboration tools which can help the students in the collaborative knowledge building in classroom and after class. It is convenient to use, powerful, and a good assistant of both the teaching and learning.* », therefore Padlet, [5], was chosen to experience a collaborative activity to engage students. Nevertheless, there are other platforms where similar activities may be proposed, *e.g.* Google Jamboard, Miro, Moodle, etc.

K. Lee (K. Lee, 2014 [6]) states that "*It may be advisable for teachers to develop students' learning processes in the face-to-face context without technology before engaging them in technology-supported learning*."

With this activity proposal authors wanted to have a clear perception of several aspects, namely:

1. Do students really engage into collaborative platforms?
2. Do these platforms help students to obtain better results?
3. Do students prefer individual help given by a teacher, for example office hours, when they need to clarify some questions?
4. Are students willing to help they fellow colleagues in the learning process?

2 METHODOLOGY

2.1 Padlet Activity Proposal

An activity was proposed over a semester to students of Statistical Methods from Informatics Engineering. This curricular unit enrols 533 students, 85 on an after-work basis. The objective of this proposal was to create a collaborative learning platform, as described above, where students could interact with each other within the scope of the curricular unit. Cumulatively, it was an objective that students deepen the topics taught in class, including references provided, and reviewing exercises conducted by their colleagues.

Questions from previous exams were regularly proposed in a Padlet where students who register to participate, duly identified (Name and number of student) can publish their resolutions, comment (constructively) on the resolutions published by colleagues.

The proposed questions were taken out from all previous exams of the curricular unit since one of the aims was to support students on their learning path. The typical study path followed by our students is 1) To study theoretical concepts (definitions, applied theorems, examples given in class); 2) Solve the exercises proposed at Exercises Curricular Unit booklet; 3) Solve previous exams. With this activity teachers were aiming to help on steps 1 and 2, since step 1 is discussed inside class. One example of questions proposed in the Padlet activity is provided in Appendix I.

Student ratings are a calculated proportion of the number of participations in different content. Of all the participations made by the student, the one(s) that has the highest number of correct participations in the largest number of different contents, has the highest rating. Example: From X distinct contents, the student correctly solves 1 exercise of content A and 1 exercise of content B - will have in the final classification (2/X) * 2 bonus values. The student correctly solves 2 exercises of content A and 0 exercises of content B - will have in the final classification (1/X) * 2 bonus values. Participation in exercises of the same content, despite not having bonuses in the final classification, has the goodness of cementing the personal study of the student and collaborating in the study of the group involved.

Professors corrected the materials published by the students providing feedback either if the students' resolution needed to be redone or if it was correct.

All students who participated had access to all the work developed. At the end of the activity, the students involved could obtain at most 2 points that were added to their final classification mark. The evaluation of students' involvement, collaboration, and solidarity in addition to the results will be discussed and presented in the results' section. Figure 1 shows the Padlet activity proposed.

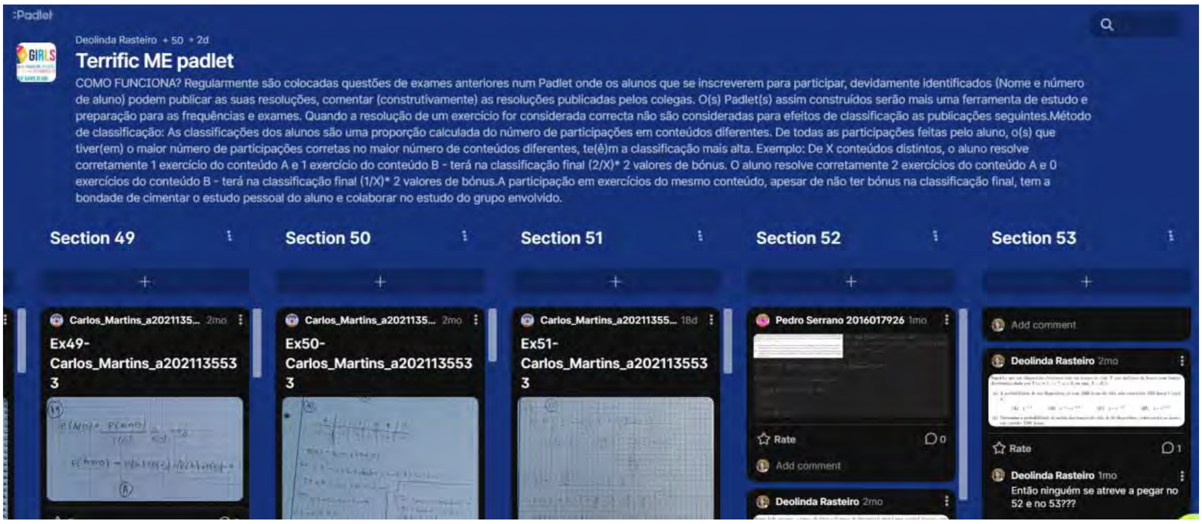

Fig. 1. Padlet activty.

The period of observation of the activity was from 18/03/2023 to 28/04/2023. After the activity a *GoogleForms,* [6], questionnaire was filled by the students in order to gather their opinion about it.

The questions made are within table 1 below, possible answers were yes/no.

Table 1. Satisfaction Questionnaire

Questions
Have you ever used Padlet before?
Do you consider that, in addition to the Bonus, which you may have in your classification, this activity helps you to study?
Do you consider that, in addition to the Bonus, which you may have in your ranking, this activity helped you to obtain a better ranking in the written assessment?
Was the feedback given by teachers sufficient?
Was the feedback given by your colleagues sufficient?
Would you like there to be more interaction with and from your colleagues? (comments and questions to your resolutions)
You agree to share the published resolutions with all your colleagues registered in the curricular unit?

2.2 Working Sample

Registered to Statistical Methods curricular unit were 533 students (85 of them on a after work basis). To all students an invitation to inscribe themselves on the Padlet activity was sent by e-mail and available at the Moodle curricular unit page during a period of two weeks at the beginning of the semester. From the 533 students, 137 showed intentions to participate, 28 of which from the after-work course. Thus, approximately 24.3% of regular the students and 33% of after work students engaged on this activity (≅ 25.7% of the total students registered on the curricular unit). Although 137 showed intentions of participating, only 50 indeed posted and interacted with their fellow colleagues.

3 RESULTS

3.1 Padlet posts, satisfaction questionnaire and written assessment

The first result that was indeed not encouraging was the starting index of engagement, only 25.7% of the students responded to the activity invitation, even though 2 bonus points could be achieved in the end.

Considering the period of observation (from 18/03/2023 to 28/04/2023) we had 448 posts and their distribution by day may be observed in Figure 2 below.

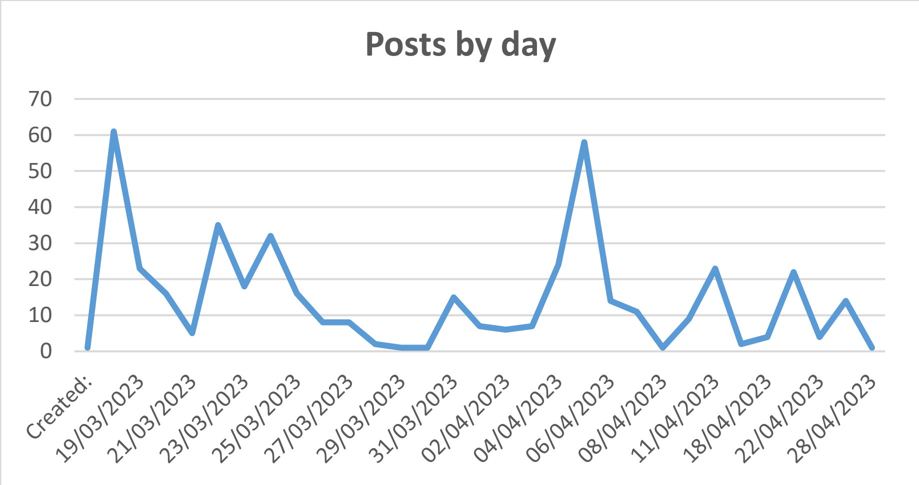

Fig. 2. Distribution of posts by day

The distribution of posts by Exercise entrance is depicted on Figure 3, below. As we may observe, in the beginning there was a higher response rate that may be attributed to two different reasons: one is natural curiosity, the other is because initial exercises were simpler that the following ones.

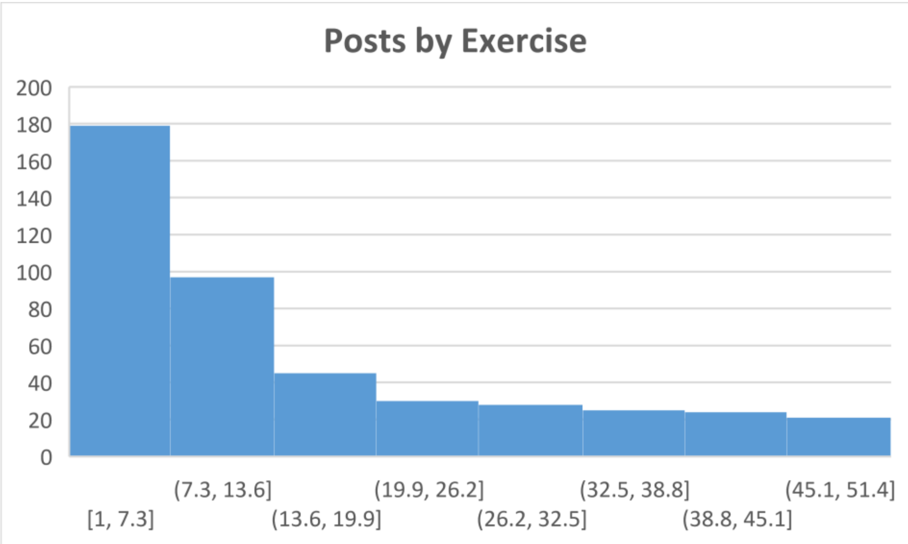

Fig. 3. Posts by Exercise

Since the response rate stabilized during the period of observation and the exercises difficulty were regularly improving, the authors tend to justify the initial index of response as curiosity.

The questionnaire using *Googleforms*, Figure 4., that was proposed to the students allowed teachers to obtain their opinion about satisfaction and utility of the Padlet activity.

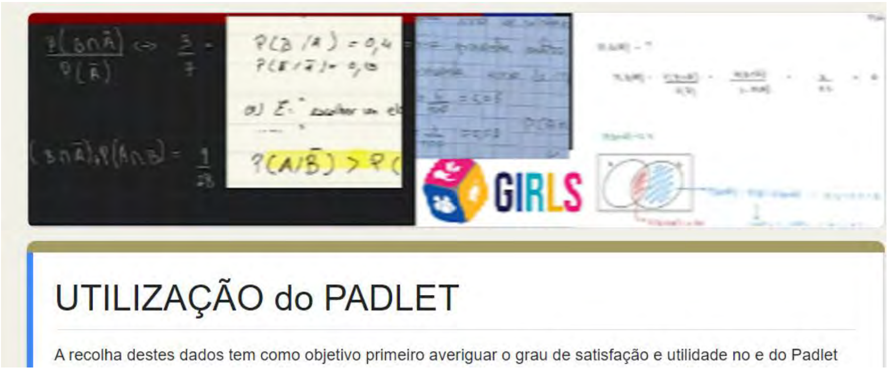

Fig. 4. Posts by Exercise

From the data collected and resumed we conclude that 60% of the engaged students had never used Padlet. Since the activity engagement in the beginning was only approximately 25.7%, the authors questioned if the students were only involved because of the 2-points bonus proposed. All 100% students agreed that this activity helped them to study besides the 2-points bonus proposed. When asked «*Do you consider that, in addition to the bonus, which you may have in your mark, this activity helped you to obtain a better classification in the written assessment?* », *the* obtained answers indicate, as shown in Figure 5., that 73.33% of the students consider the activity has helped them to prepare to the written assessment.

To corroborate these received answers, we compared the number of students approved in the written assessment to the number of those students that participated in the activity.

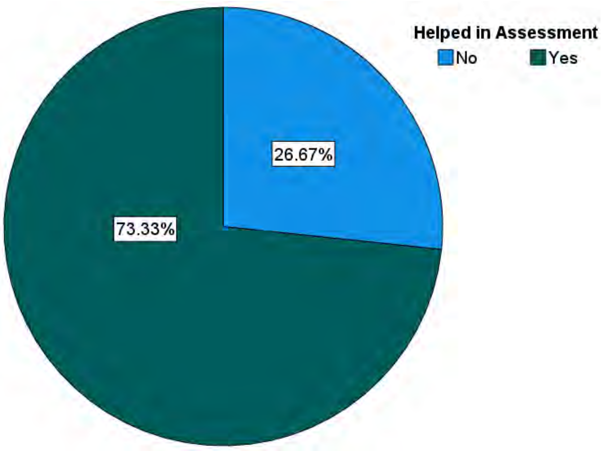

Fig. 5. Positive activity influence in the assessment

In fact, in case of after work students, from the 44.71% of the ones that were assessed, 60.53% approved, and from those 60.78% participated in the activity. Regarding regular students, from the 43.90% of the ones that were assessed, 70.09% approved, and from those 37.80% participated in the activity.

Table 2. Statistics from the written assessment

After Work Students Total	85	
Assessed	38	44.71%

Approved	23	60.53%
In_Activity	14	60.87%
Regular Students Total	533	
Assessed	234	43.90%
Approved	164	70.09%
In_Activity	62	37.80%

Regarding the feedback given by professors, 100% of the students considered that it was enough, while 13.3% of them wished that colleagues gave more feedback. All 100% considered the materials posted by their fellow colleagues were of help to complement their own study.

When asked «*Would you like there to be more interaction with and from your colleagues? (Comments and questions to your resolutions*)*?* », 40% of the students wished more interaction from their colleagues.

Finally, professors, to be able to conclude whether students' solidarity was only towards the colleagues participating in the activity or in general, asked the students «*Do you agree with the sharing of the published resolutions with all your colleagues enrolled in the course?* » and all 100% agreed.

4 CONCLUSIONS

From this activity a couple of conclusions may be redrawn. The first conclusion is that the percentage of students engaged in this activity was below professors' expectation and the percentage of students that undertaken the written assessment was also surprising (≅51%). Students prefer to clarify their questions about contents and exercises resolution at office hours or by e-mail where the only intervenient are the professor and themselves. Therefore, individual study is preferred by the student's majority. Other conclusion is that, even though we have faced times where ICT was widely used, Padlet, which is a very know collaborative platform was an unknown tool for 60% of the students. All 100% students agreed that this activity helped them to study, and the feedback provided by professors was enough. A small percentage, 13.3%, of the students wished that colleagues gave more feedback.

To share their collaborative work with all the other students is, for the students engaged in the Padlet activity, not a problem. Therefore, we may conclude that although a small percentage of students wishes to work in collaboration, those who want are 100% solidary with all the others.

Regarding future work with Padlet, authors intend to continue with this resource but using a different approach. It will be also used as a tool inside and outside the classroom. We believe that this approach will involve more students in the collaborative learning process.

5 ACKNOWLEDGMENTS

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APPENDIX I

This appendix contains some figures with examples from the exercises proposed to students in the Padlet activity

Let Ω be the space results associated to a random experience. Consider that A and B are two events ($A \subset \Omega$ and $B \subset \Omega$) such that $\mathrm{P}(A) = 0.6$, $\mathrm{P}(\overline{B}) = 0.6$ and $\mathrm{P}(A \cap B) = 0.4$. The value of $\mathrm{P}(B/\overline{A})$ is

(A) 0 **(B)** $\frac{1}{3}$ **(C)** $\frac{2}{3}$ **(D)** 1

A student will take 3 exams. The probability of having a positive grade in each exam is 0.6 and the exam results are independent. Calculate the probability of the student having a positive grade:

(a) in the maximum of two exams;

(b) in the first and third exams only.

The number of defects per article produced in a certain production line follows a *Poisson* distribution with an expected value of 0.01. To be sold, these articles are packed in boxes of 10 units.

(a) The probability of any article not being defective is

(A) 0.9900 **(B)** 0.9048 **(C)** 0.0952 **(D)** 0.0100

(b) The probability that, in a box, the total number of defects found is greater than 2 is

(A) 0.0001 **(B)** 0.0013 **(C)** 0.0002 **(D)** 0.9957

In a factory, there are two production lines for an article (X), and the article is classified regarding its final quality (Y), according to the following table:

X Y	1	2	Total
1	0.06	b	0.25
2	0.04	c	e
3	a	d	0.4

(a) Knowing that $P(X = 2 \cap Y = 3) = 0.25$, complete the table missing values.

(b) Knowing that an article was rated 3 regarding its final quality, determine the probability that it was produced by production line 2.

(c) From the sentences below choose the one that is true

(I) The higher the number of the production line, the lower will tend to be the classification in terms of final quality;

(II) The higher the number of the production line, the higher the classification will tend to be in terms of final quality;

(III) The final quality classification is independent of the production line number.

(Although this question is a multiple choice, please indicate all the calculations you performed.)

The time that an employee, a hypermarket cashier, takes to serve a customer follows an exponential distribution of an average of 5 minutes.

(a) The probability of a customer takes less than 4 minutes to be served is

(A) 0.7135 **(B)** 0.7769 **(C)** 1 **(D)** 0.5507

Observation: If needed, $\int_a^b f'(x)\, e^{f(x)}\, dx = e^{f(b)} - e^{f(a)}$

(b) Assume that 50 customers paid for their purchases in this hypermarket cashier. What is the probability of the average service time is less than 5 minutes?

. Consider that there are four consecutive steps of processing and analyzing images for further integration into *apps*. The average time spent in each of these steps by algorithm A is, respectively, 10.5, 10.8, 10.4 and 10.7 milliseconds. It is assumed that the times spent in each step are independent and have normal distributions whose standard deviations are, respectively, 0.2, 0.4, 0.4 and 0.6.

(a) Set a maximum limit on the time spent by algorithm A in 95% of cases.

(b) If the total time spent in the 4 steps by algorithm B follows a normal distribution of mean 42.6 milliseconds and variance 0.9, the probability of this algorithm being faster than algorithm A is, using 4 decimal places,

(A) 0.3187 **(B)** 0.4376 **(C)** 0.5624 **(D)** 0.6813

. An investor is interested in a financial asset and needs help to make the decision. The investor will only invest if the average financial return (expressed as a percentage) is greater than 3.4%. To help him make the decision, a sample corresponding to the financial return of 41 transactions was collected, whose average is 3.9% and the standard deviation is 1.3%.

(a) With 98% confidence, what would you indicate to the investor?

(b) Subsequently, the standard deviation was questioned by business partners who claimed not to support the decision if the standard deviation was greater than 1.2%. At the significance level of 5%, and assuming that the financial return follows a normal distribution, find out if the investor will have the support of its partners in the decision taken.

. In a given curricular unit, the time in hours that a student spends to study for an exam is associated with a random variable X, with the probability density function given by $f_\alpha(x) = e^{-x+2\alpha}$, $x > 2\alpha$, where α is an unknown parameter related to the minimum study time to approve in the exam. It is also known that $\mathrm{E}(X) = 1 + 2\alpha$.

(a) A random sample of X, $X_1 X_2, \cdots, X_n$ with $n > 2$ was collected. An unbiased estimator of $\alpha > 0$ is

(A) $\dfrac{\overline{X} - 1}{2}$ **(B)** $\overline{X}$ **(C)** $\dfrac{\overline{X}}{2} - 1$

(b) A sample of X, of size 200, whose average is 50 hours, was collected. From this sample an unbiased estimate of α is

(A) 24hours **(B)** 50hours **(C)** 49hours **(D)** 24, 5hours

Teach as you Preach:
Teacher Training for STEM Educators at DTU

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Conference Key Areas: *Innovative Teaching and Learning Methods & Curriculum Development*
Keywords: *Constructive Alignment, Teacher Training, Active Learning, STEM in Higher Education, Sustainable Learning Processes*

ABSTRACT

At technical universities today, we are training students for jobs that do not yet exist, to use technologies that have not been invented, to solve problems, we do not even know are problems yet. To succeed, we must create sustainable learning processes allowing our students to construct proper conceptual understanding and be able to retrieve, transfer, and apply knowledge, skills, and competences in new complex settings.

To facilitate such learning processes, higher education institutions must train excellent teachers. This paper presents the framework for STEM teacher training at DTU – Technical University of Denmark. A framework that claims exactly to train excellent teachers by practicing what we preach: Employing a student-centred approach focusing on student motivation with active learning and constructive alignment to ensure conceptual understanding.

Rather than presenting long theoretical lectures to the participants of our teacher training programme, we – from day one – ask them to engage in a range of carefully planned activities designed to scaffold the construction of sustainable knowledge, skills, and competences that can be activated in unknown future contexts. Exactly as we wish for them to do with their own students.

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1 INTRODUCTION: THE TEACHER TRAINING PROGRAMME AT DTU

”For many university professors, teaching is like being handed the keys to a car without being taught how to drive. […] The unstated assumption is that if you have a degree in a subject, you must know how to teach it at the college level.”[2]

However, at DTU – Technical University of Denmark, we strive to educate not only the best graduates, but also excellent teachers.

The teacher training programme at DTU is called UDTU. UDTU equals approximately 250 working hours and can be completed within a year. Each year, approximately 60 participants take part in the teacher training-programme. In this paper, we refer to DTU-students taking part in a bachelor, a masters or a Ph.D.-programme as *students*. We refer to the assistant professors, post. docs and senior researchers taking part in the teacher training programme as *participants*.

UDTU has two foci, namely:
1) The design of a DTU course and
2) The development as a university teacher.

We, the facilitators of the UDTU programme, offer *just-in-time teaching* and supervision, and throughout UDTU, participants carry out a number of teaching and learning activities. The activities are tasks done individually, in pairs, triads, and in groups of four to six peers.

During the first semester of UDTU, the participants take part in several facilitated sessions with a duration of one to three days. These sessions focus on teaching methods, didactical design, feedback, assessment, constructive alignment, and motivation. During the second semester of UDTU, the participants try out and evaluate the DTU course they have designed during the first UDTU-semester.

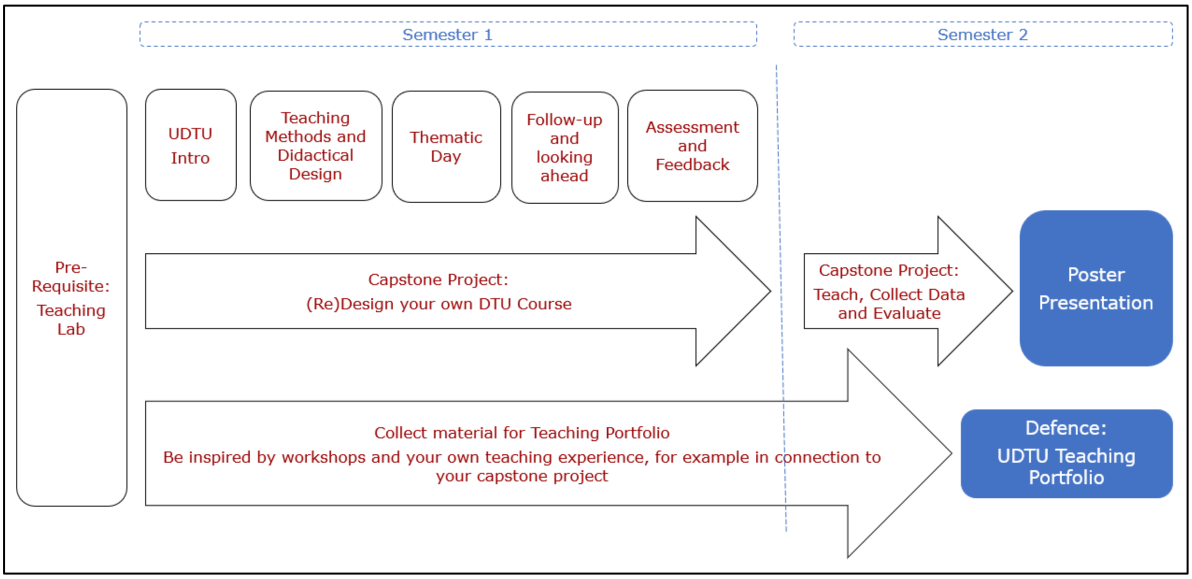

Fig. 1. UDTU Roadmap

[2] Felder, Richard M. and Brent, Rebecca. *Teaching and Learning STEM A Practical Guide*. San Francisco: Jossey-Bass, 2016, XV, I.

The overall learning objectives of the UDTU programme can be seen in Figure 2.

- Plan, teach, develop, and evaluate student-centred and learning outcome-based teaching at DTU.
- Design a teaching sequence, preferably an entire DTU course, using innovative teaching methods and didactical design to promote student motivation and scaffold student learning and conceptual understanding.
- Design a DTU course using constructive alignment and formative feedback to support students as self-regulated learners.
- Reflect on and continue your development on becoming an excellent DTU Teacher.
- Contribute to the development of courses and educational programmes in higher education.

Fig. 2. UDTU Learning Objectives

The design of the UDTU programme is inspired and informed by *constructive alignment* (developed by John Biggs[3]), the *Theory of Didactical Situations in Mathematics* (developed by Guy Brousseau[4]), and the *model of student motivation and persistence* (developed by Vincent Tinto)[5].

In this paper, we describe the overall teaching philosophy and the didactical design of the programme with a focus on constructive alignment, other aspects of the UDTU programme will be covered elsewhere. First, we outline the overarching teaching philosophy of the DTU Learning Lab. Then we introduce constructive alignment along with examples of how this is practiced in the UDTU programme.

2 TEACHING PHILOSOPHY AND DIDACTICAL CONTRACT

The overarching teaching philosophy of the DTU Learning Lab is *Granny's Law* as formulated by Danish researcher, Steen Larsen. Granny's Law stipulates "the person, who works, learns. Period."[6] Thus, for the UDTU participants to learn, they must do the work – by actively engaging in teaching and learning activities.

At the outset of the UDTU programme, we establish a strong *didactical contract* with our participants. During the facilitated sessions, we have just-in-time teaching, but no regurgitation of literature read as preparation. The didactical contract is developed by French mathematician Guy Brousseau and clarifies the responsibilities of the facilitators and the participants[7]. The didactical contract states that learners must learn, and teachers must create space and opportunity for learning to take place[8].

The UDTU participants must design a DTU course with carefully thought-out, high-level learning objectives. They design worthwhile and productive teaching and learning activities guiding the students towards their learning outcomes and lastly, the courses must have suitable formative feedback and summative assessment of student learning and learning outcomes. Thus, the UDTU programme itself is designed exactly like that - according to the three pillars of good teaching and learning at DTU (figure 3 below).

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[3] Biggs, John and Tang, Catherine. *Teaching for Quality Learning at University.* New York: Open University Press, 2011.

[4] Brousseau, Guy. *Theory of Didactical Situations in Mathematics*. Dordrecht Boston: Kluwer Academic Publishers, 1997.

[5] Tinto, Vincent. "Through the Eyes of Students." *Journal of college Student Retention: Research, Theory & Practice* 19, no 3 (2017): 254-269.

[6] Larsen, Steen. *Den ultimative formel for effektive læreprocesser*. Hellerup: Steen Larsen, 1998, 37 (own translation).

[7] Brousseau, Guy. *Theory of Didactical Situations in Mathematics*. Dordrecht Boston: Kluwer Academic Publishers, 1997, 227ff.

[8] Skott, Jeppe and Jess, Kristine and Hansen, Hans Christian. *Matematik for lærerstuderende*. Frederiksberg: Samfundslitteratur, 2008, 421.

3 BASIC PRINCIPLE: CONSTRUCTIVE ALIGNMENT

Although constructive alignment as an educational concept has existed since 1999, it is our experience that it has not consistently been implemented in higher education. For this reason, UDTU has a strong focus on both the theoretical model and practical demonstration of constructive alignment, essentially, we teach as we preach.

Constructive alignment is the notion of American learning theorist, John Biggs, that the learning objectives, the teaching and learning activities, and the assessment should be *constructively aligned* to support one another[9].

In other words, each and every educational element should have clearly defined learning objectives stipulating what the students should be able to do after the completion of e.g., a course, a lecture, an assignment or a project in terms of knowledge, skills, and competences. At DTU, we use Bloom's revised taxonomy of educational objectives when formulating learning objectives[10] (see figure 4 below).

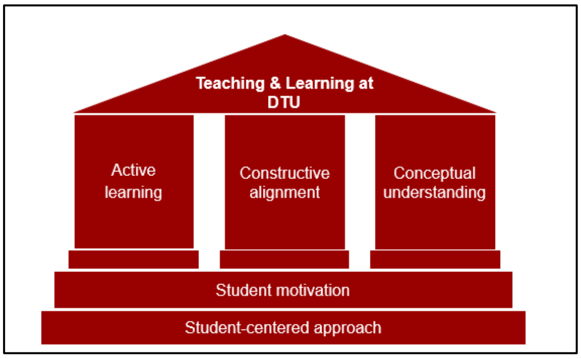

Fig. 3. Pillars of good teaching and learning at DTU

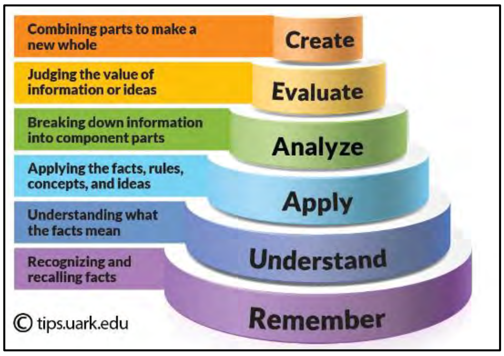

Fig. 4. Bloom's revised taxonomy[11]

To guide and support students to achieve the learning objectives, teaching and learning activities should be carefully designed. These activities could include teaching, preferably as just-in-time teaching, tasks, and assignments for students to work with individually and in groups, projects, fieldwork, lab exercises, and experiments. While taking part in the carefully designed teaching and learning activities, the students will acquire the knowledge, skills, and competences stated in the learning objectives. Following this, the exam should evaluate the extent to which the students have indeed met the learning objectives.

Students will learn whatever it takes to pass the exam. This is known as the *backwash effect*, which is the observation that the exam of a course washes back and guides the student behaviour and learning outcome[12]. If alignment and overlap between the assessment and the learning objectives is not present, students will merely learn what it takes to pass the exams. If we want our students to construct a

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[9] Biggs and Tang *Teaching for Quality Learning.*

[10] Krathwohl, David. R. "A Revision of Bloom's Taxonomy: An Overview." *Theory Into Practice* 41, no. 4 (2002): 212-218.

[11] Shabatura, Jessica. "Using Bloom's Taxonomy to Write Effective Learning Outcomes." University of Arkansas Tips. University of Arkansas, July 26 2022. https://tips.uark.edu/using-blooms-taxonomy/

[12] Andersen, Hanne Leth and Tofteskov, Jens. *Eksamen og eksamensformer. Betydning og bedømmelse*. Frederiksberg: Samfundslitteratur, 2016, 19.

proper conceptual understanding and formulate this as an overall learning objective for the course, it should not be possible to pass the exam without a proper conceptual understanding.

3.1 Constructive Alignment in the UDTU programme

As mentioned, the UDTU programme has two foci: the participants' development as a teacher and their design of a DTU course. Throughout their UDTU journey, the participants make two products: a UDTU Teaching Portfolio and a Capstone Project Poster. The Teaching Portfolio is the vehicle of the first focus, and the Capstone Project is the vehicle for the second focus.

The overall assessment of UDTU has been carefully thought out to assess the extent to which the participants have achieved the learning objectives of the programme. Furthermore, and perhaps more importantly, the intention is to activate a measure of sustainability in the sense that the products continue to live after completion of the UDTU programme, outside of the UDTU ecosystem in contributing to the development of the teaching practice at DTU more broadly and reach into the future of both the individual teacher, and STEM higher education as a field of practice.

3.2 Teaching Portfolio

"*The Teaching Portfolio is by far the most interesting and useful exercise [at UDTU]."*
Former participant at UDTU

The Teaching Portfolio is an ongoing document that follows the teacher throughout their teaching career. At UDTU, we encourage our teachers to work actively with their portfolio already during their asynchronous preparation for the first facilitated session, throughout UDTU as part of planned activities, and finally as a product (the UDTU Teaching Portfolio) on which they will be assessed.

The format for Teaching Portfolios at DTU is inspired by the "model for Teaching Portfolio in engineering education" published by the IUS (Ingeniør Uddannelsernes Samråd), a collaboration among all technical universities in Denmark[13].

The continuous work with the Teaching Portfolio – and the final creation of a UDTU Teaching Portfolio – address the following overall learning objective of UDTU: *Reflect on and continue your development on becoming an excellent DTU Teacher.* On a more specific level, we have operationalised the overall learning objective into the five learning objectives illustrated in figure 5. After the evaluation, defence, and acceptance of the participants' UDTU Teaching Portfolio, they will have reached these five specific learning outcomes.

- Present how your current teaching philosophy informs your teaching practice.
- Reflect on how your perception of teaching and learning has developed over time.
- Show how your ongoing observations of student behaviour and feedback contributes to the development of your teaching practice at DTU.
- Make reference to relevant literature from educational science to describe how you support student learning and develop your teaching practice.
- Demonstrate how collegial observation of your own and your peers' teaching practices influence the continued development of your teaching practice.

Fig. 5 Learning Objectives for the UDTU Teaching Portfolio

[13] Sass, Ditte Strunge. "UDTU" Learninglab.dtu.dk. Technical University of Denmark. Access date: 05.07.2023 https://learninglab.dtu.dk/courses-and-events/udtu?accordion=8

3.2.1 Activities supporting the Learning Objectives of the Teaching Portfolio

During UDTU, we work with an intentional backwash effect, meaning that we begin the programme by showing our participants where they will end. It has been shown that "students learn more and retain their knowledge longer when they engage in deliberate practice focused on clear and specific goals"[14]. In practice, we do this at the introduction day of UDTU, when we discuss the two final products on which the participants will be assessed. In terms of the Teaching Portfolio, we ask our participants to watch two short videos that explains the purpose, structure, and assessment of the UDTU Teaching Portfolio. This allows us to do a just-in-time teaching session focussing on their questions, rather than on a presentation of the portfolio with respect to purpose, content, and assessment.

At each subsequent facilitated session, the participants are invited to reflect on the development of their teaching philosophy, choice of methods and teaching practice in different ways – through walk and talk activities, drawings, reflection questions and one-minute papers. We use open reflection time actively to strengthen learning outcomes; participants create an ongoing working portfolio in which they compile a record of their understanding of the methods, models, theories, and activities that they have engaged with throughout the UDTU programme. Asking them to actively reflect on what appeals to them and why, along with what does not, we aim to encourage a high degree of *transfer* of knowledge. The idea about transfer of knowledge was formulated by educational psychologist David Ausubel and refers to e.g., the design of didactical situations that allow learners to learn in a meaningful way, making it possible to activate knowledge in unknown future complex contexts[15].

At our final facilitated session, we set aside time for the participants to give each other 1:1 peer-feedback on pre-prepared UDTU Teaching Portfolio drafts. Based on the formative feedback, the participants revise and re-submit for further anonymous and formative peer feedback within our Learning Management System.

3.2.2 Assessment of Teaching Portfolio

A Teaching Portfolio should not merely document teaching experience or knowledge of educational theory, but rather show competencies. To do so, we ask our participants to produce a *UDTU Teaching Portfolio,* which is a document (max. five pages) that consists of three parts: 1) Teaching philosophy, 2) Teaching methods and 3) Teaching practice description.

To make the document come to life, the participants must focus on the dynamic relationship between the three as they inform and are informed by one another. This dynamic is ensured by including the participants' personal reflective reasoning as they make choices to use (or not use) a certain method/practice and by showing us how feedback from their practice, their students and colleagues influence their development as teachers.

The final product, the UDTU Teaching Portfolio, is assessed at a cluster defence according to a rubric, which is based on the five learning objectives of the Teaching

[14] Ericsson in Felder and Brent *Teaching and Learning STEM,* 25.

[15] Ausubel, David P. *Educational Psychology. A Cognitive View*. New York: Holt, Rinehart and Winston, 1968.

Portfolio. The cluster defences are held four times/year allowing participants to sign up when they have amassed enough teaching experience to reflect on. The defence is a conversation on the strengths and improvement areas in the submitted portfolios. It takes place in clusters of 4-5 participants and is facilitated by educational consultants from DTU Learning Lab. The participants can pass, pass with corrections, or fail and hence re-submit and re-defend their portfolio.

Our intent with the Teaching Portfolio was to create a summative assessment of the knowledge acquired by our participants during their UDTU journey, yet with a flavour of formative feedback as it should point into the future and provide a foundation for their ongoing development as teachers. At first, some participants find it difficult and frustrating to reflect upon their own teaching practice. After completing the UDTU programme, however, they find their Teaching Portfolio and written reflections not only useful for their continuous development as teachers, but also rewarding. Based on the feedback from our participants, we believe the Teaching Portfolio to be a relevant and meaningful product evaluated in a constructively aligned way supported by relevant and meaningful teaching and learning activities.

3.3 Capstone Project

"I have made several changes to my course during my capstone project. Reflecting on these changes, I think the biggest success has been a clear improvement in my active use of learning objectives and the implementation of constructive alignment in every aspect of the course."

Former participant at UDTU

The Capstone Project is the design of a DTU course (during and between the facilitated sessions), followed by the implementation of the course, testing, collecting data on students' learning outcome and finally evaluating the course in view of future development. The Capstone Project address the overall learning objectives of the UDTU programme illustrated in figure 6.

- Plan, teach, develop, and evaluate student-centred and learning outcome-based teaching at DTU.
- Design a teaching sequence, preferably an entire DTU course, using innovative teaching methods and didactical design to promote student motivation and scaffold student learning and conceptual understanding.
- Design a DTU course using constructive alignment and formative feedback to support students as self-regulated learners.
- Contribute to the development of courses and educational programmes in higher education.

Fig. 6 Overall UDTU Learning Objectives related to the Capstone Project

3.3.1 Teaching and Learning Activities Supporting the Capstone Project

To support participants achieving the learning objectives and ensure constructive alignment, all activities during UDTU have been scaffolded around the creation of the two primary products. On the introduction day of the UDTU programme, we begin by asking our participants to formulate an overarching research question that they will be working on throughout their UDTU journey as they design a DTU course. This could be an overall challenge, problem and/or focus area that they will be researching during their Capstone Project.

All subsequent activities are scaffolded in relation to their research question and the design of their DTU course. Several activities will support them to develop their course directly, as they discover methods and models to apply and test in their courses. Other activities will indirectly influence their design, as they also encounter methods that they actively do not wish to use. Participants are encouraged to reflect on how choices are informed by, and in turn inform, both their teaching philosophy and the design of their course.

3.3.2 Assessment of Capstone Project

Each participant presents the major findings of their capstone project at a bi-annual poster event. These events are the culmination of all the hard work the participants have put into the UDTU teacher training programme. All DTU employees are invited to participate to be inspired to develop their own courses and teaching.

The posters are pre-approved for presentation by educational consultants in DTU Learning Lab according to a rubric, where the overarching learning objectives for UDTU have been translated into four learning outcomes as illustrated in figure 7.

- Present a clear research question and the activities you have undertaken to address this in the (re)design of your DTU course.
- Analyse, evaluate and reflect on the major findings from teaching your newly designed DTU course with respect to student learning.
- Utilize feedback from colleagues and students to improve your teaching and future development as a teacher at DTU.
- Participate in higher education discussions on how to develop teaching, learning and educational programmes.

Fig. 7 Learning Objectives for the Capstone Project Poster

At the poster event, the participant is assigned a station where to present their poster. In parallel tracks, each participant has ten minutes to present their poster, followed by ten minutes for questions. At the end of all presentations, the audience vote for a best poster. The dean of Undergraduate Studies and Student Affairs presents the award for the elected best poster and gives a closing speech to mark that this is indeed an occasion for celebrating the participants contribution to: the development of teaching and learning and educational programmes at DTU, higher education discussions in general and not least their own development as teachers.

4 SUMMARY

"*The UDTU is really fun. A good journey."*
Former UDTU-participant

As mentioned, "The unstated assumption is that if you have a degree in a subject, you must know how to teach it at the college level."[16] However, if our participants have no teacher training what can and will they do? Other than copy and replicate the least bad teaching they experienced when they were university students themselves. This leads to reproduction of (very) traditional monologue lecturing.

A UDTU-participant stated that he taught very traditionally, before taking part in UDTU: *"I must admit I regret this way of teaching. Not only is this uninspiring, but it also promotes superficial learning and a lack of attention. It is not an understatement to say that UDTU has inspired me to improve!"*

What we have achieved overall, by practicing constructive alignment, is to support and disturb the UDTU participants to focus on their students and the students' sustainable learning processes and outcome – rather than on themselves as lecturers and the content and their lectures and PowerPoint-presentations.

[16] Felder & Brent *Teaching and Learning STEM,* I.

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EXPERIENCE WITH REMOTE LABORATORIES FOR ON-CAMPUS ENGINEERING DEGREES

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ABSTRACT

Remote laboratories extend the teaching and learning opportunities available for on-campus courses, by increasing the overall capacity for practical work and enabling new types of activities. We present three case studies from different types of usage within the School of Engineering at the University of Edinburgh over the last three academic years. Each case study provides an overview of the experimental hardware and user interface, the learning context and reflections on their development from our perspective as providers of the system. The case studies include a pendulum lab that provided large cohorts of students access to lab equipment in a traditional classroom setting with in-person peer-to-peer and peer-to-staff interactions, but with remote equipment; a truss lab that was used to provide live lecture demonstrations and real-world data for tutorial questions ; and a spinning disk lab that allowed students to complete assessed coursework during the Covid-19 pandemic. Our remote laboratories have been successfully used under both pandemic and post-pandemic conditions, with ongoing usage growing. The software and hardware is open-source so as to enable adoption by a wider community of users.

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1 INTRODUCTION

Many traditional university campuses continue to face pressures from increasing student numbers, with the amount of in-person laboratory work limited by the available physical space. A continued perception of a skills gap in UK engineering graduates (Armitage & Bourne, 2020) indicates there may be significant value in expanding the amount and type of practical work available to support students in their learning. In other subjects, it has been shown that graduates valued more highly those educational tasks that most closely represented aspects of their professional practice (Wood et al., 2015). Furthermore, the Covid-19 pandemic has raised global awareness of the value of diversity in working modes and patterns, such as by making education remotely accessible (Graham, 2022). An aspect of education that is non-trivial to deliver remotely is practical work, due to the technical complexity of the underlying infrastructure required to deliver at scale. However, the drivers above have contributed to a renewed consideration of remote laboratories for traditional campuses (Drysdale et al., 2020).

Remote laboratories consist of real hardware accessed and controlled via a web browser. They provide the opportunity for students to attempt practical work from any (internet connected) location at any time and have been shown to provide positive learning outcomes for students (Post et al., 2019). Remote lab hardware can be physically located in spaces not normally associated with practical work, such as public foyers in campus buildings, where multiple copies of the hardware can be efficiently installed. In this way the aesthetics of the public spaces and visibility of institutional activities are increased, all without taking up limited teaching laboratory space. Remote laboratories have been shown to have advantages over simulated labs, with students reporting increased trust in data, motivation and perception of the veracity of the experience when using remote laboratories (Jona et al., 2011) and learning outcomes are better (Corter et al., 2011). Engineering students also need to understand how real-world factors add noise and variability to their data and this natural variability enables the type of authentic inquiry that is missing in simulated labs, even when variability is programmed in (Jona et al., 2011). Although remote laboratories remove the hands-on manipulation of physical hardware, the learning intentions of engineering labs cover a wide range of skills, including data analysis, comparison to theory and communication (Feisel & Rosa, 2005), and students report ‘no significant difference’ or ‘easier with a remote lab’ for demonstrating the majority of lab skills (Reid et al., 2022). When learning intentions are specifically focused on psychomotor skills then a traditional lab format should be used; however, direct manipulation of hardware is not a necessary condition for the development of other practical skills (see Brinson, 2015).

The School of Engineering at the University of Edinburgh has begun embedding remote labs in its on-campus degree programmes, using the *practable.io (Drysdale et al., n.d.)* remote lab infrastructure being developed there. The *practable.io* infrastructure has been described in (Reid et al., 2022) and is available open-source in order to encourage the adoption, and ease the burden of development, of remote labs at other institutions.

The remainder of this paper describes three case studies that provide details of specific remote lab implementations and how they have been used to meet a teaching and learning need that would be difficult with traditional, in-person access to practical hardware. This includes how traditional classroom spaces can be used for practical lessons (case study 1); how remote access to equipment provides opportunities for live data collection during lectures and tutorials (case study 2); and how assessed coursework was possible during the Covid-19 pandemic (case study 3).

2 METHODOLOGY

We present case studies exploring three different ways in which remote labs can be integrated into on-campus degree courses. These case studies are presented from our perspective as providers of the remote laboratory facilities. The teaching exercises were developed by course organisers and teaching staff. Each case study focuses on a single remote laboratory exercise and includes:

- an overview of the experiment
- a description of the learning context
- a reflection on the development process

3 RESULTS

3.1 Case study 1: Pendulum lab (in-person, in classroom)

The pendulum lab (Fig. 1) consists of an electromagnetically driven pendulum and an encoder for measuring angular position. Students are able to control the driving amplitude, braking strength, sampling rate and can compare forced braking (‘brake’ mode) with self-induced loading of the coil (‘load’) and free, natural decay (‘free’). Pendulums allow students to investigate many aspects of periodic motion, including: variations in period with amplitude, exponential decay parameters, how sampling rate affects measurements, and how the remote lab pendulum compares to periodic motion theory. Students are also able to make ‘analogue’ measurements of the pendulum using on screen ruler and protractor tools (see Fig. 1). A scale placed in the webcam view allows students to manually calibrate the ruler tool to make accurate measurements of objects in the webcam view.

Our pendulum labs provided experimental measurement and uncertainty activities to a large (450-student) first year course, without needing dedicated laboratory space. Students were located in traditional classrooms and accessed the remote hardware via their own laptops on the university’s Wi-Fi network. A series of sessions over two days allowed all students to access the practical work, with parallel sessions resulting in approximately 60 connections to the remote lab system at any one time. We repeated this in two different weeks focusing on different aspects of the task.

Fig. 1. User interface for the pendulum remote lab, showing webcam view, analogue measuring tools and graphing components.

The students also had access to the spinning disk lab, described in the third case study. We had already designed the pendulum experiment as a demonstrator for the concept of remote laboratories and for use in open days for outreach. After showing the course staff the experiment they iteratively developed a set of tasks that would suit the educational goals of the course. Now that the course team have successfully delivered this experience at a large scale we are working together on developing new hardware to create an additional experiment.

Figure 2 shows how pendulum and spinner remote lab usage varied across the hours of the day. Data was collected between 02/03/2023 and 19/06/2023, which includes the second week of the sessions described above. These sessions ran between the hours of 14:00 and 18:00, hence the peak in access across those hours. However, a major benefit of remote access to hardware is evident in the extension of lab usage outside of usual university working hours. The insert in Figure 2 shows the different operating systems used to access the remote labs during this same period. Desktop/laptop connections (Windows, Mac, Linux and ChromeOS) make up the vast majority of connections; however, the user interfaces have been designed to accommodate mobile usage (Android, iPhone, iPad) as well.

3.2 Case study 2: Truss lab (lecture demonstrations, tutorials & assignments)

Our truss remote lab (Fig. 3) consists of a six-member truss with each beam having a full-bridge strain gauge arrangement using two biaxial strain gauges and a linear servo to produce a load force on the truss. Users have control over the load (within safe limits) by positioning the servo and can tare the strain gauges and load cell. Data is displayed on the user interface as an overlay on an image of the truss, with values in micro-strain ($\mu\varepsilon$) for gauge measurements and as a force (N) for the load cell. Users can also capture a snapshot of all measurements in a table, graph different permutations of gauge and load cell data, and display theoretical strain measurements based on the measured load force. A set of eight truss experiments were prepared.

A structural mechanics course was looking for the opportunity to provide students with live demonstrations and data for calculations during lectures and tutorials. In a previous iteration of the course, before remote labs were available, students only had access to a single truss in a teaching laboratory. They would physically load the truss and take measurements from a digital interface. With only a single truss available, throughput was limited and it could not be demonstrated during lectures due to the difficulty in transporting it.

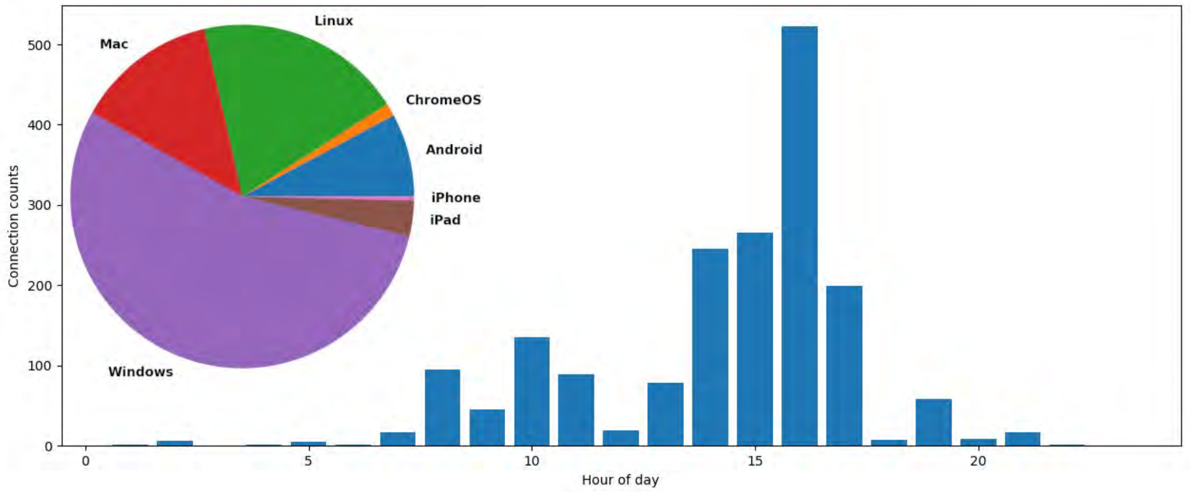

Fig. 2. Usage data across the hours of the day for the pendulum and spinner labs between March and June 2023. Insert shows the operating systems that users are accessing the labs from.

With adoption of the remote lab version, the trusses could be demonstrated live in lecture theatres to show the real-time behaviour of the beams when loaded. During tutorial sessions in traditional classroom settings, students were given access for 10 minutes (extended if necessary) to one of eight trusses to collect strain data for a set position of the load mechanism. They were then asked to calculate the load force that would produce those strain results. During classroom use of the truss lab, the UI did not reveal load forces or theoretical comparison values. After calculations were performed and submitted, students were given access to the fully featured UI so that they could explore the lab further in their own time. Rather than using the same fixed example dataset for all students, remote access to real experimental setups provide the opportunity for students to utilise live data for calculations, with the potential for multiple, unique hardware setups to produce variation in students' collected data. For example, we have additional truss experiments awaiting construction using different beam materials.

Through careful design of the user interface, remote labs provide an opportunity to scaffold a student's interaction with the hardware based on the context and learning intentions. For example, the UI can show data required for a calculation, but delay revealing the measured quantity that students are attempting to predict. We also developed UIs for other contexts, such as with potential university applicants during open day events. There we used a UI with an alternative control scheme that simplified the explanation given by the demonstrator. Timely development of new activities is made possible, in part, by the use of web app frameworks like Vue.js, where reactive UI components can be shared between remote lab implementations. The open-source license of our software also means that adopters are not tied into a specific lab configuration, allowing for re-design of firmware and user interfaces to suit local institutional requirements, if necessary.

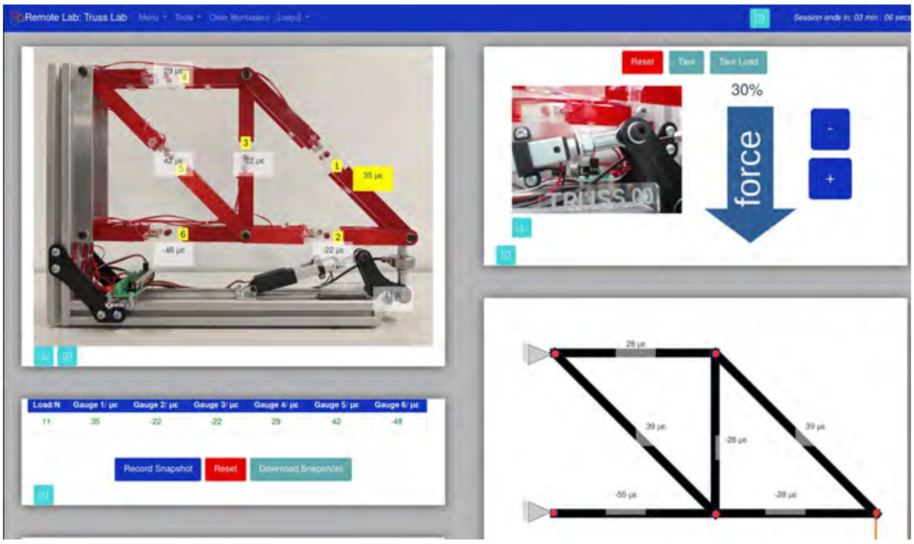

Fig. 3. Truss remote lab user interface in "open day" configuration, providing all data, simple control and theoretical comparison.

3.3 Case study 3: Spinning disk (individual asynchronous access)

The spinning disk remote lab was developed to allow students to investigate the application of proportional-integral-derivative (PID) controllers. These controllers are widely used in industry for controlling mechanical movement, regulating speed and managing the temperature of chemical processes. The principles are similar for each application so students can be taught them using any convenient type of hardware. The remote lab hardware comprises a brushed DC motor, optical encoder and a weighted disk that allows students to explore position control and speed control. The user interface allows students to configure the controller and run various position and speed control tasks of their own devising. There are limits encoded in the firmware to prevent potential damage from over-speed and excessive oscillations. To show students what is happening in the experiment, encoder data is collected every 5ms and sent for display on the user interface. Students can see and manipulate the data in multiple ways, using the data snapshot, table and graphing tools. The data can also be exported as a CSV file for analysis in external software, such as Excel or MATLAB. It is important for students to observe the effect of changing the angular inertia (size and weight) of the disk. This lab has a set of 12 differently dimensioned aluminium disks (4x each set in its current format making 48 spinner labs available), the details of which are provided to students via the webcam view. Students were assigned two different weighted disks for their assessed coursework.

The first use of the spinning disk lab for teaching and learning allowed control systems laboratory work to be conducted during the Covid-19 pandemic, when traditional lab work was not possible and students were restricted to locations outside of the university. Students were able to access the remote lab on any internet connected device via the browser, allowing students to complete assessed coursework with very few modifications to the in-person version of the lab. Beyond giving students access to the (likely) only practical work they had during the pandemic restrictions, the remote lab allowed 10-20x more experimental time for each student compared to the previous version of the lab in a traditional setting. Students reported that the ability to manage their own time during remote lab usage was a major advantage of the system (Reid et al., 2022).

Figure 4a shows the cumulative hours of student use of the spinning disk lab in the second year it ran (2022), reaching approximately 2500 hours for N ≈ 250 students, i.e. 10 hours per student. Previously, the in-person exercise offered three hours per student, in groups of six, for a total of 750 student-hours of experimentation, but only 125 student-hours of *one-to-one equivalent time* with the equipment. We arrive at the latter figure by dividing the total time by the group size. Hence the remote lab not only tripled the total student-hours, but increased the equivalent one-to-one time by a factor of 20. In some settings, group work is pedagogically motivated, while in others it is a result of resource limitations so a comparison of one-to-one equivalent time is appropriate. Since the time students spent on the remote labs was set by them, our data may indicate a significant gap between the supply and demand of laboratory time in traditional laboratory settings where resource constraints are a dominant factor. We also noted that students used a range of session lengths from the options available (Figure 4b). We only offered the 90 min session for the first two weeks, to manage demand, however this was unlikely to affect the popularity of the 5 min sessions, so we conclude that offering a range of session times is likely to better match student preferences. We are now also able to offer longer sessions again because in 2023 we implemented session cancellation.

Over the course of three years, feedback from student and staff usage has continually driven the development of this remote lab. Feedback has also led to the updating of our booking system from first come, first served to a system allowing for future booking, pre-booking for whole classes and cancellation of bookings (Reid & Drysdale, 2023) whilst maintaining a freely available pool of labs when they are not assigned to courses. We can also set the time intervals bookings can be made for and the number of concurrent pieces of hardware any single user can book.

Feedback from staff has highlighted the importance of testing hardware against the intended learning outcomes of the course. In the first academic year, we tried a number of different configurations for the weighted disk in an attempt to demonstrate all of the control theory principles required. Our first attempt used pennies as variable weights but the small slop necessary for making them removable introduced an unacceptable degree of non-linearity. Similarly, the friction in the original motor resulted in variability from run to run and obscured the steady state error that occurs depending on the type of input (step or ramp). In year 2 we upgraded the motors so that this large, compulsory Year 3 class could focus on understanding the ideal response with fewer complicating real-world factors. In our view, the original experiment design would be useful for a more advanced class where the introduction of real world, non-idealities is in the intended learning outcomes.

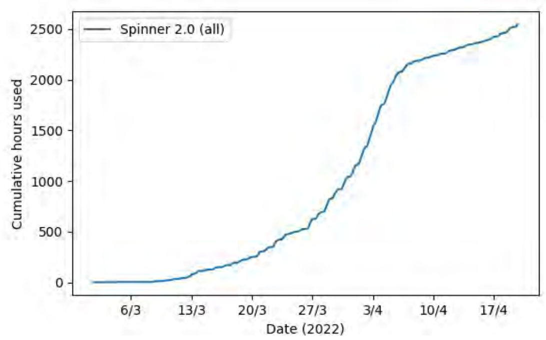

Fig. 4a. Spinning disk cumulative hours used between March and April 2022.

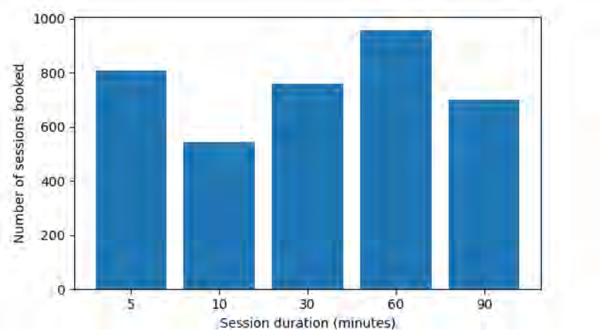

Fig. 4b. The number of sessions booked for each possible session duration (5, 10, 30, 60 and 90 mins).

4 SUMMARY AND ACKNOWLEDGMENTS

We have described three possible use cases of remote labs for engineering education, providing an insight into the unique opportunities afforded by the use of remote labs for on-campus degree programmes. We found that remote labs provide a complementary set of teaching and learning opportunities to in-person lab experiences, with remote labs enabling more time for student exploration of hardware; access to real equipment outside the space and time confines of the traditional lab setting; and an opportunity to help scaffold student learning through the re-mixing of user interfaces for specific contexts.

We are grateful to the following course organisers and staff for developing the teaching materials and co-developing the hardware and/or user interfaces: Jonathan Terry and Brian Peterson (case study 1), Thomas Reynolds and Marcelo Dias (case study 2), Aristides Kiprakis (case study 3), and Symon Podilchak and his research team (electromagnetics, to be the subject of a future publication). Michael Merlin proposed the pendulum control method. Andrew Brown designed the mechanical hardware and built the experiments together with Calum Melrose. Imogen Heard contributed to the electronics design. Additional essential support was provided from Technical, Buildings, IT, and Professional Services staff. The work was funded by the School of Engineering, University of Edinburgh. The remote lab infrastructure is open source and available at https://github.com/practable.

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INCLUSION IN COMPUTING VIA THE EARLY RESEARCH SCHOLARS PROGRAM AT UIC

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ABSTRACT

For a sustainable world, all people who aspire to be engineers should have an equitable opportunity to achieve their engineering education. In the United States, groups of individuals continue to be minoritized in engineering and computing

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specifically. This practice paper addresses inclusion and diversity efforts in the computing field, within two departments of a college of engineering, to 1) increase the number of minoritized students in computing, 2) introduce research as a career path to undergraduates early on in their education, and 3) nurture a sense of community (within the department and the computing field) for students. These efforts are being furthered through the Early Research Scholars Program, which is a program to engage students with research within their first 3-4 semesters in their undergraduate careers. In this paper, we will review aspects of this program that make it inclusive and harness diversity, share preliminary results from the last two years on community building within the program, and provide implications for other institutions to implement inclusive and community-building practices in their curricula or programming.

1 INTRODUCTION

1.1 Inclusion and Diversity in Computing

Inclusion and diversity efforts in STEM fields in the United States are ongoing and have been a focus of discussion for many years (Tsui 2007; Museus et al. 2011), with a multitude of national reports addressing or highlighting this issue. While other fields within STEM have made some strides in improving diversity, computing fields, and especially in industry, have not (Johnson and Miller 2002). Within computing specifically, which includes fields of Computer Science, Computer Engineering, Data Science, and Software Engineering, inclusion and diversity efforts are crucial given the heightened and relatively recent interest in these fields. This interest paired with the underrepresentation of women and racial/ethnic minoritized students (i.e., Black, Latinx, and Indigenous) in computing makes it necessary to address this issue. Inclusion and diversity efforts targeted toward undergraduate students in computing generally address the following areas: harnessing a sense of belonging (Lewis et al. 2019; Gates et al. 1999), addressing structural needs such as financial aid and career-building support (Bego and Nwokeji 2021), connecting their major and career to personal values (Brinkman and Diekman 2016).

To address inclusion and diversity in computing, efforts to improve upon these areas have sprouted in the form of curricular changes, extracurricular engagement, and support, as well as some policy changes. In this paper, we discuss efforts to improve upon inclusion and diversity within computing fields via curricular changes through an undergraduate research program completed in the early years of undergraduate education. This program was started at the University of California San Diego (Barrow, Thomas, and Alvarado 2016) and recently implemented at various institutions across the United States (Alvarado et al. 2022).

1.2 Institutional Context

The University of Illinois, Chicago is located in an urban setting, the university is a research-intensive Minority Serving Institution. Although the university is diverse and there is no racial/ethnic majority group, diversity within computing majors (i.e., Computer Science, Data Science, Computer Engineering) does not fully reflect the institution's diversity. Similarly, women and non-binary students are underrepresented in computing majors. The majority of students in the College of Engineering at the University of Illinois, Chicago are non-residential students with a significant percentage (almost half) being transfer students.

The Early Research Scholars Program started at the institution in 2019 and is currently in its fifth year running. The program is split into two semesters: in the first semester, students take an introduction to research course, and in the second semester, students work on their research program directly with their research mentor. Every year, there have been ~25 undergraduates in the program. There has been steady participation from faculty in both departments housing the program over the years, with an increased interest in Computer Science and most recently Data Science. Table 1 provides an overview of the student demographics that this program has served since 2019.

Table 1. *Student Demographics & Retention*

Year	# of Students	# of Women and Non-Binary	# of Black, Latinx, Indigenous	Program Retention (Fall to Spring)
2019-2020	28	22	5	93%
2020-2021	29	21	7	97%
2021-2022	30	17	9	90%
2022-2023	25	11	7	84%

2 METHODOLOGY

2.1 Program Components that Promote Inclusion and Diversity

While more in-depth details of the entire program are provided elsewhere (Alvarado et al. 2022), in this section we will review program components that are specifically incorporated to promote inclusion and diversity in computing. This program's components include:

- **Application Components**: Students have to apply to the program by providing some demographical information, as well as writing three short essays. Two of these short essays are specifically instituted to elicit reflection about diversity and hardship.
- **Targeted Recruitment:** While acceptance to the program is open to any student eligible for the program, we emphasize targeted recruitment via inclusion-drive entities within the College of Engineering to ensure a diverse pool of applicants. These entities include retention and recruitment programs, women in engineering programs, women-focused student organizations, and ethnic student organizations in computing. Additionally, targeted communications are sent to minoritized students in computing who are encouraged to apply.
- **Recruitment of Central Mentors**: Central mentors are critical to the success and feeling of inclusion in the program. As a result, there is targeted recruitment and selection of central mentors. Central mentors are selected from one of the two departments that house this program, which includes computing majors. The central mentors are identified by the program directors and sometimes with the help of other faculty in the departments. Central mentors help undergraduates not just succeed in their respective research projects, but also feel a sense of belonging within the fields. Central mentors have a fundamental understanding of research in computing, strong communication skills, an understanding of the need for inclusion and diversity and computing, and an ability to advise and guide using an ethic of care (Noddings 1988).
- **Recruitment of Faculty Mentors**: Similar to the recruitment of central mentors, faculty mentors are purposefully recruited. Program directors make concerted efforts to identify faculty mentors who have a track record of a) working with undergraduates on research, b) understanding and supporting the need for inclusion and diversity in computing, and c) are committed to the goals of the program.
- **Class-Based Reinforcements:** In the fall semester introduction to research class, in-class activities that reinforce inclusion and diversity in the form of

community building and boosting self-belonging are included. These activities include team-building exercises, dialogue about research and being researchers, 1-1 chats with students about their journey in computing, and peer-feedback activities to reinforce community building.

- **Research in a Team:** Akin to the affinity-group model (Gates et al. 1999), the Early Research Scholars Program aims to promote community-building by establishing research work via teams. Students are teamed up by project interest as well as availability. Different from other undergraduate research programs, working on a research program as part of a team encourages students to build connections and avoid feeling isolated or alone in doing research. Throughout the program, the central mentor and program director support the teams through any challenges or conflicts that might arise to ensure that community building can be prioritized.

2.2 Reflection Study

To assess the impact of the program on students, we collected ~monthly reflections throughout the academic year. In this paper, we share preliminary results from the reflections surrounding the sense of belonging and feeling supported. The reflection prompts for these questions were: In what ways does your team help or hinder your feeling of belonging in your field?

The reflections were collected via Qualtrics and are currently being analyzed using MAXQDA software. The guiding research question for this analysis is: How does the Early Research Scholars Program impact a student's feeling of inclusion in computing? We performed a thematic analysis of the students' reflections to answer the research question.

A major limitation of this reflection study is that the reflections were purposefully not graded or given class credit therefore those who completed the reflection did so very lightly. As a result, we have a number of reflections that consist of only a couple of sentences per question/prompt.

3 PRELIMINARY RESULTS

3.1 Student Reflections

The thematic analysis is not yet finalized; as a result, in this paper, we share our preliminary results. What we are finding so far is that the team aspects of the Early Research Scholars Program help students feel connected not just to one another, but also to the computing field. In addition, as can be noted by some of the quotations below, some students feel connected to their team not just because of computing, but also because of the shared gendered experiences.

> *My team consisted of all girls that supported one another and always made me feel like I belonged in Computer Science. They celebrated and were proud of my achievements, and thus they made us feel like I really belonged to be a part of Computer Science. Spring 2020*

Students in the program generally feel supported in computing by others in their teams. This support is sometimes personal and academic and sometimes in the process of doing research.

They are incredibly talented in computer science and sometimes I feel imposter syndrome but they never bash me or make me feel less them despite being behind or different. Spring 2021

3.2 Evaluation Results

The initial evaluation findings revealed that students demonstrate a strong comprehension of research after their first semester in the program. In keeping with the program's objectives, the majority of participants in the Early Research Scholars Program possess no prior experience in conducting research, despite harboring a strong interest. Students evinced an understanding of the scope and nature of research, distinguishing it from other classes from their curriculum, while some have even gained insight into the research process itself. We attribute this success to students' competence and attitudes in engineering; that understanding the research process is a crucial step towards developing the ability to conduct research and ultimately gaining proficiency as engineers or computer scientists.

The Center for Evaluating the Research Pipeline, an arm of the Computing Research Association, conducts an annual assessment of the Early Research Scholars Program. The first evaluation of the Early Research Scholars Program at UIC indicated that students in the program exhibited increased levels of experience with research, collaborating with colleagues on research projects, data analysis, and presenting research findings, six months following their completion of the Early Research Scholars Program. Nearly all students reported a favorable impact of the Early Research Scholars Program on their identity as an engineer, computer scientist, or researcher; however, measures such as student self-efficacy and sense of belonging did not show significant statistical differences in the evaluation report. Nonetheless, personal, academic, and professional reflections submitted by students during the program demonstrated that their sense of belonging and identity have been positively impacted by the program.

Some student reflections indicated a desire for improved coordination with research mentors and a more evenly distributed workload in the research methods course, which will be addressed in the program's fifth iteration.

4 SUMMARY AND ACKNOWLEDGMENTS

The Early Research Scholars Program is focused on improving diversity in computing by promoting community building and an enhanced sense of belonging through engagement in undergraduate research. This program provides undergraduates an opportunity to engage with peers, graduate students, and faculty early on in their undergraduate years in a meaningful way that affirms students' belonging in computing and promotes inclusion. We believe the aspects of the program that harvest diversity and inclusion can be translated to other institutions as well as other types of activities within higher education such as curricular and extracurricular activities.

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CRITICAL CONSCIOUSNESS AND ENGINEERING DESIGN TEACHING FRAMEWORK

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ABSTRACT

Sustainability in engineering design is not just about the processes and practices established or the materials used and sourced, it is also about the mindset that

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engineers bring to design to carry forth solutions that promote a sustainable world. In this practice paper, we review a teaching framework for an engineering course on design with a contextual perspective. To contextualize engineering design, we incorporate critical consciousness topics to discuss alongside each design process topic. For example, during the unit when we discuss design alternatives in the engineering design process, we also discuss implicit bias and how implicit bias may impact the alternatives that engineers promote in the design. These critical consciousness topics allow for a dialogue that is rooted in history and an understanding of engineering design outside of a vacuum. An adaptation of this course is being taught at two different higher education institutions in the United States. In this paper, we share this teaching framework along with some examples of how we're implementing the framework as well as preliminary results from our study of what impact this work has on students' critical consciousness gains.

1 INTRODUCTION

1.1 Critical Consciousness in Engineering Design

Sustainability in engineering design is not just about the processes and practices established or the materials used and sourced, it is also about the mindset that engineers bring to design to carry forth solutions that promote a sustainable world. Concurrently, there is a lack of focus in engineering design courses on socio-cultural aspects of design, and not only user-driven design. Although more humanistic aspects of the engineering design process have recently been incorporated (Mann, Radcliffe, and Dall'Alba 2007; Zoltowski, Oakes, and Cardella 2012) as it stands, the teaching of engineering design is not focused on the contextual understanding of the social, cultural, economic, and political systems that surround it (Leydens, Lucena, and Nieusma 2014). Nor does it typically cover the gendered and racialized experiences of engineers involved in the design or cases where designs have led to products or industrial processes that are inequitable, oppressive, or unjust (Benjamin 2019; Costanza-Chock 2020; Ozkan and Hira 2021). Here, we differentiate our course from human-centered design courses in that our course does not only highlight the individuals impacted by the design but integrates a critical analysis of how the design enables injustice towards specific individuals and groups of individuals. Moreover, using critical consciousness as the driving concept for our course, we aim to teach design with action at the forefront of our pedagogy. In other words, our course asks students to consider what actions they will plan to take as engineers in light of the knowledge learned.

1.2 Critical Consciousness in Teaching

One of the goals of this course is to provide a contextual perspective to all students about sociocultural and political factors that impact design. In some cases, especially for minoritized engineering students, such a perspective may validate the experiences and knowledge they bring with them to their institution in the pursuit of their engineering career. While not all students may have the language to describe their oppressive experiences, they might have had to develop strategies to manage these experiences. For example, McGee and Martin (2011) discuss how Black students in science and engineering use their understanding of racism in order to manage stereotype threat and its negative effects. By using critical consciousness in the design curriculum, we hope to increase students' understanding of social injustices as they relate to engineering and as they relate to their personal journeys of engineering education.

1.3 Institutional Context

There are two 4-year, higher education institutions in the United States involved in this project. Both institutions are categorized as research-intensive and have the Hispanic Serving Institution designation granted by the Department of Education.

One of the institutions, City University (pseudonym), located in the U.S. Midwest, is urban, non-residential, and serves a large number of low-income students. The College of Engineering at this institution is a mid-size college with ~4200 undergraduate students enrolled. Almost half of the undergraduate students are transfer students from community colleges. The student body in the College of Engineering during the Fall of 2020 semester was 23% female, 22% first-generation, 24% Latina/o, Hispanic students, 5% African American, 25% Asian American. About half of all engineering undergraduate students are transfer students. With regard to engineering design, all departments in the College of Engineering at City University offer a senior design capstone course. There is variation in how the senior design capstone courses are taught across departments in the college. In some departments, students work with private industry while in others they work with faculty or other campus entities. While capstone engineering design is instituted in the College of Engineering, mid-year (or early years) engineering design is not.

The second institution, Metropolis University (pseudonym), is located in a city in the U.S. Southwest, one of the largest metropolitan areas in the United States. More than 69% of Metropolis University's 30,674 students are from historically marginalized groups, of which 53% are Latinos/as/xs. Nearly half of undergraduates (45%), will be the first in their family to earn a bachelor's degree. Transfer students comprise about 38% of the undergraduate population. Similar to City University, Metropolis University's College of Engineering also offers a senior capstone design course for all engineering and architecture majors. Although some students incorporate social, economic, or environmental aspects into their designs, these are not typically at the forefront nor are these requirements that should be integrated into their projects. There are no engineering design courses in the mid-years or opportunities to do design projects that incorporate social, political, economic, or environmental components into the design process.

2 METHODOLOGY

2.1 Teaching Framework

One of the goals of this project is to develop a teaching framework that incorporates critical consciousness in design. To do this, we also added intergroup dialogue as a component of our framework. "Intergroup dialogue work is a process designed to involve individuals and groups in an exploration of societal issues about which views differ, often to the extent that polarization and conflict occur" (Dessel, Rogge, & Garlington, 2006, p. 304). "Intergroup dialogue is public process designed to involve individuals and groups in an exploration of societal issues such as politics, racism, religion, and culture that are often flashpoints for polarization and social conflict" (Dessel, Rogge, & Garlington, 2006, p. 303). It can provide a safe space to share or express issues related to injustice meanwhile harboring a space where fruitful discussion about injustice can be had across groups. Intergroup dialogue can be used as a mechanism through which engineering students can engage with individuals to advance advocacy, justice, and social change. Some characteristics of intergroup dialogue involve fostering an environment that allows participants to share their experiences, establish communication relationships, facilitate dialogue, and encourage collaborations between participants. Intergroup dialogue is designed to provide a safe and structured opportunity to explore issues that can be sometimes polarizing. Various techniques and strategies (Nagda 2006; Zúñiga and Nagda 2001) fare employed to ensure that a safe space can be established in the classroom to allow for intergroup dialogue.

The working teaching framework is illustrated in Figure 1. This framework is currently being improved, with continued improvements through 2025. The teaching framework includes three core components: critical consciousness (CC), engineering design, and intergroup dialogue (IGD).

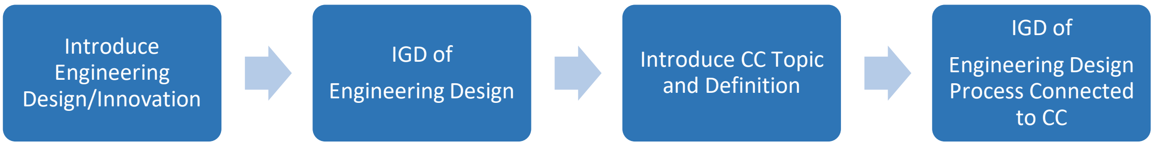

Fig. 1 Teaching Framework

Critical consciousness is used both as a guiding concept to frame the course material and also as a way to inform topics that are included in the course. The focus on raising critical consciousness enabled us to choose aligned topics that would promote cognitive dissonance, discussion, and liberation. It is important to note that the selected topics have been reported in the enginering education literature as topics that often contribute to the normalization of Western-based, Eurocentric values that may perpetuate ideals of disengagement in engineering (Cech 2014). Some of these topics are shown and described in Table 1.

Table 1. List of Representative Critical Consciousness Topics That Guided our Teaching Framework

Critical Consciousness Topic	Description
Militarism	The history of engineering as rooted in military efforts and the contemporary influence of military-driven goals for engineering, as discussed in (Riley 2008)
Globalization	The global-level analysis of impact of engineering design and systems.
Technocracy and techno-determinism	The prioritization and influence of technology on society and individual values as well as on the field of engineering.
Color evasiveness	Originally coined as « color blindness » by (Bonilla-Silva 2017) and operationalized as ignoring experiences or differences based on race, ethnicity, or skin color.
Representation	The need for representation of all people in the field of engineering, specifically in engineering design.
Decolonization	An analysis of engineering as a field that can be understood from non-dominant ideologies.

The engineering design process was taught throughout the semester in a linear-like manner, although iteration and feedback were reinforced throughout. The major aspects of the engineering design process were broken up by teaching unit, and these included: problem scoping, requirements, design alternatives, testing, prototyping, and iteration.

Finally, intergroup dialogue was used as a tool to promote discussion and reflection in each class around the critical consciousness and design topics presented. As a result, intergroup dialogue is weaved into the whole course and purposefully made visible to the students throughout the semester.

2.2 Implementation

This teaching framework was implemented in two courses, one at each institution involved in this project. The courses at both institutions were taught by a singular faculty member and ran for the duration of a 15-week semester. At City University, a 2-credit hour course in the Department of Electrical and Computer Engineering was offered in Spring 2023. This mid-year course was designed for sophomores (equivalent to a traditional second year in college) and juniors (equivalent to a traditional third year in college) majoring in Electrical Engineering, Computer Engineering, or Engineering Physics. There were 16 students enrolled in the course in Spring 2023. The class met once a week for 2 hours. As part of the course, students worked with a community organization from a neighborhood in the vicinity of the university. At Metropolis University, a 3-credit hour course housed within the College of Engineering was offered in Spring 2023. The class meets twice a week for 75 minutes. This course was designed for first-year College of Engineering students and was open to all science, technology, engineering, and mathematics (STEM) majors although the highest number of students came from the College of Engineering. There were 40 students enrolled in the course, which sought to explore the impact of modern technologies on society. It is important to note that a central aspect of the course was the teaching of fundamentals of engineering design, which was also used as a segway to explore the roles of engineers in decision-making processes. Finally, we should note that at both institutions, the course was advertised as a design course taught alongside a contextual perspective.

In general and across both institutions, the flow of each unit followed in Figure 1, wherein an engineering innovation was introduced via the use of videos, readings, or graphics. The engineering innovations discussed were picked by the instructors to elicit conversations around the design and critical consciousness topics taught in each respective unit. These innovations, when relevant, were also contextualized during the discussion and often problematized to allow for a rich discussion and reflection of the intersection of design and critical consciousness. Some examples of these innovations included: cobalt mining for lithium battery design, the accuracy of facial recognition software, and exclusionary user interface design in gaming controllers. While these examples were gathered from various resources across time and disciplines, a significant number of these examples and their impact on society can be found in works by Benjamin (2019) and Costanza-Chock (2020).

2.3 Assessment

The work presented in this paper is part of a larger project; thus, in this paper, we focus on the assessment of the teaching framework. The assessment of the teaching framework was primarily informed by student reflections, instructor reflections, and student interviews, all of which have IRB approval at our respective institutions. Currently, we share preliminary results on student and instructor reflections.

As part of the course, students were asked to complete ~weekly reflections to answer the following questions: 1) What were some of the arguments, discussions, or facts that interested you the most/least this week? Why? 2) What could an engineer do to implement any of the concepts/topics learned this week to engage in better design practices? 3) How is your understanding of critical consciousness changed, if at all, after this week's class? Remember, critical consciousness is the way in which you perceive the world around you (e.g., engineering and technologies, communities, behaviors, etc.) and the possibilities of taking action to challenge the dominant structures that create the world that surrounds you. The student reflections were collected using Qualtrics and analyzed using MAXQDA and NVivo.

Similarly, every week, instructors were asked to complete a reflection addressing the following questions: What went well? Reflect on teaching, and reaction to material with respect to critical consciousness, learning outcomes, IGD activities. What did not go as planned/as well? Reflect on concerns of implementation of teaching, learning outcomes, reaction to material with respect to critical consciousness, IGD activities. These reflections were done in a Word document and analyzed using MAXQDA and NVivo.

Finally, students were invited for a post-interview with a researcher (not the course instructor) in each respective institution. The interview protocol covers a few topics, but relevant to this paper, the interview protocol includes questions about the impact of the course on the student's critical consciousness. While student interviews are finalized, analysis of these interviews is ongoing and will be shared in a future manuscript.

3 PRELIMINARY RESULTS

3.1 Student Reflections

The students were prompted to reflect on their identities as engineers during the lectures and activities, which proved to be sometimes challenging for the students. They were asked to envision their professional life as engineers and members of society and grappled with questions about the future role they would play as decision-makers. The reflective process provided by Intergroup Dialogue and related activities was profound and allowed them to think about the social, political, and cultural aspects of engineering, as well as the economic, environmental, and historical implications of engineering work. Furthermore, they were encouraged to question issues of power and put their critical literacy skills into practice as they deconstructed the reading materials provided to them.

Most of the student reflections indicated that they appreciated having the space to talk about these issues since these are topics that are rarely discussed in engineering courses. In addition, students discussed the complexity of approaching and solving engineering problems, which was one of the goals of the course – to show students that engineering is interconnected with different systems of power and oppression that create the complexity in which we live. Some students also had conflicting perceptions about social justice and engineering. For example, some students indicated that ethics and social justice were difficult to distinguish concepts because other engineering courses often talked about ethics but not about social justice. Students viewed social justice as a minor aspect of ethical responsibility in engineering, and sometimes completely unrelated to the field. By utilizing intergroup dialogue, students were given the opportunity to reflect on their stance and shift from a culture of disengagement to a more insightful and holistic understanding of their environment. Through this continuous process, students were able to contemplate how engineering design could be approached from a different viewpoint.

3.2 Instructor Reflections

Analysis of instructor reflections is undergoing; however, our preliminary results point to the benefits and difficulties of embedding critical consciousness into a design course. The reflections provide a sense of the collaborative work across institutions to maintain a flow of the class that allows for design activities that are grounded in critical consciousness. From the instructor's perspective, the course allowed students to have class time to openly discuss the topics in Table 1 – such dialogue was reinforced by community guidelines set early on in the class. One of the challenges in the course was that each unit was covered briefly (most done in 1 week and a couple in 2 weeks); thus, students may have felt rushed in reflecting on some topics such as capitalism – that required more background or inter-disciplinary knowledge (e.g., economics, politics).

4 SUMMARY AND ACKNOWLEDGMENTS

The aim of the course was to provide engineering students with the opportunity to expand their thinking by reflecting on a variety of issues that are important to address as critically conscious engineers. By incorporating critical consciousness and intergroup dialogue in the teaching framework of the design course, we sought to promote a different approach to the training of future engineers by creating classroom space for difficult conversations that involve engineering. It is necessary to help students comprehend not just the work of engineers as isolated subjects from society but also the social environment they are operating in. A critical consciousness teaching approach entails using critical pedagogies to break down the complexities of the engineering profession.

The use of critical pedagogies can aid engineering faculty in promoting higher levels of critical consciousness among their students. Although the engineering curriculum has not explicitly aimed for critical consciousness as an educational outcome, it is possible to investigate how it can be fostered through engineering courses following similar teaching frameworks.

ACKNOWLEDGEMENTS

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A DIGITAL LEARNING ENVIRONMENT TWIN OF A LAB ON PROTOTYPING TO GIVE ENGINEERING STUDENTS DIGITAL ACCESS 24/7

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ABSTRACT

Students do not always enjoy an in-depth practical learning experience with adequate hands-on activities during their academic education. In many fields, traditional laboratories are common learning spaces that are, however, not accessible 24/7 and the students' task is mostly pre-defined, resulting in a short and very "passive" active learning. To overcome this limitation and to provide a broader availability and to foster individual learning experience, we transformed a lab from this analog world into a digital learning and teaching environment twin. The laboratory on product design with an extensive machine park (3D-printers, CNC-carving machines, laser cutter, hand tools, etc.) is digitized and finally linked with the real-world lab. All student activities arising in the lab are transferred to the digital environment and accessible 24/7. This digitalization is implemented in Moodle incorporating mostly open-source and browser-based software to control the various machines. This results in a digital copy of the lab, its equipment, that follows the underlying product development processes and includes feedback loops and

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assessment levels for the individual progress of students – the “digital learning environment twin”.

In this paper, we illustrate the methodological approach on the established digital learning environment twin of the lab. Furthermore, we detail the transfer of analog manufacturing process to the digital world and their combination to provide a continuous digital workflow. The paper closes with an analysis of feedback (by both students and lecturers) as well as on the usability of the new digital twin.

1 INTRODUCTION

The transition from an analog to a digital learning experience is more complex in certain fields of study (e.g., engineering) than in others. This paper looks at the digitization of a laboratory used for the subject of creative prototyping in engineering education at Ansbach University of Applied Sciences, Germany. The lab is mainly used in a course on project management, where students have to design and build a wooden product of their own choice from the idea to the finished first prototype.

In recent years, it has become apparent that in many cases the production of a prototype is time-critical and depends on the availability of personnel, machine capacity and the time allocated to work in the lab. To solve these problems we developed a digital twin of the “creative prototyping” lab. This digital twin is available to students 24/7, reducing the need to be on site and minimizing fixed deadlines. The digital twin allows for greater project flexibility, allowing professors and lab staff to provide a higher-quality and more individualized support to students (who in turn improve their skills with tools and machines) [1]. In this paper, we describe the changes required to digitize the lab and connect it to the analog world and evaluate the suitability of our framework for engineering education.

First, we present the steps required to digitize the lab. This is followed by a section on the challenges posed by the analog-to-digital conversion. The paper concludes with some feedback from staff, the inclusion of the lab in the project management course, and a discussion of whether the digital lab could increase the agility of engineering education.

2 THE METHODOLOGICAL APPROACH TO THE DIGITIZATION OF THE LAB

The digitization of the lab takes place in several steps and on several levels. The main framework consists of a project management course on the Moodle learning platform of the university, a widely known and well-established environment that makes it possible to connect and digitize the individual elements needed to use the lab and the course itself.

The Creative Prototyping lab's digital learning environment can be divided into two main areas. The first area maps the product development cycle of the product management course from the initial idea to the production of the prototype (Fig. 1). The second area maps the lab itself with all the required machines, tools and documents as well as the mandatory safety training for the lab and it’s machines.

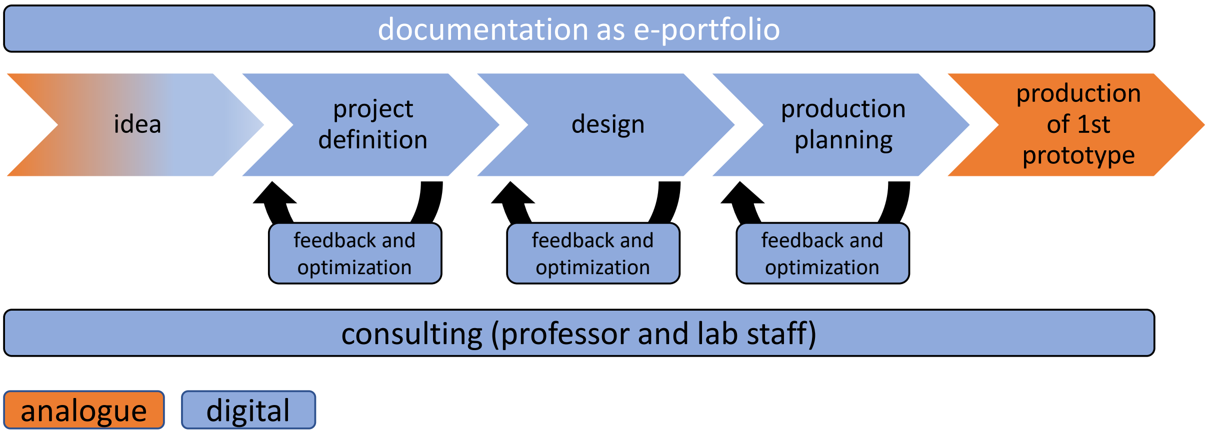

Fig. 1. Flowchart of the workflow during the course "project management"

The course on project-based product design [2], in which we tested the digitalization and usability of our prototype in the summer semester of 2022, is a required course in the bachelor's degree program in sustainable engineering at the University of Applied Sciences. We merged product design and project management to design one course that meets the demand for product design education and provides students with a satisfying first experience on project management. Students are tasked with planning, designing, and building a prototype for a wooden product (for children ages 3 and up or youths ages 16 and up) [3+4]. They are free to choose the target audience for their projects. Currently, the course is conducted and coordinated in person at set times inside the creative prototyping lab. The process is therefore completely analog and not agile.

Each intermediate step of the course has been digitized, and progress is subject to feedback loops and checks by the professor and staff. Students must complete each step of the product development cycle before moving forward. Completion of each step must be synchronized with the student's project schedule, which trains their time management skills. Their work is documented in an e-portfolio throughout the course, and their completed (digitized) project [5] is submitted using the portfolio software system Mahara [6]. Only the fabrication and physical prototype of the product idea will take place/exist in the analog world.

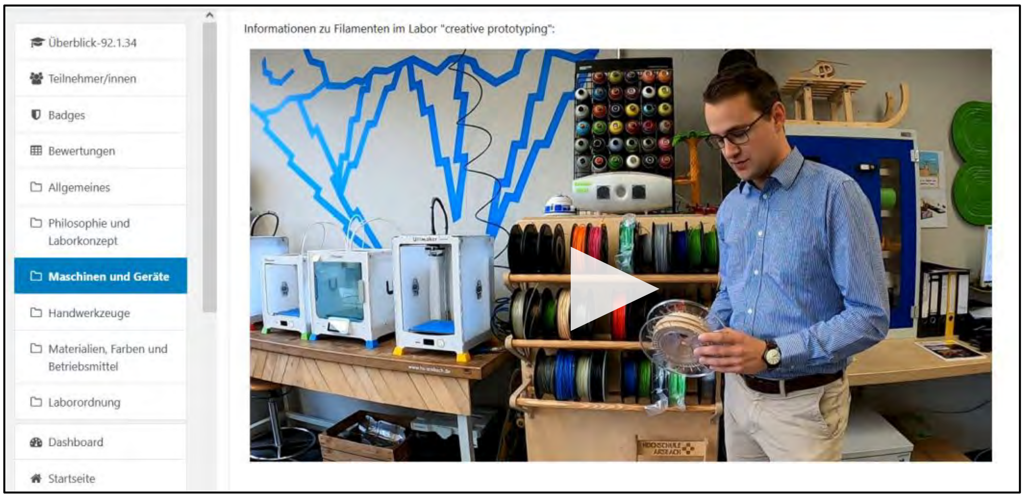

Fig. 2. Video frame of a staff member describing the attributes of filament spools for 3D printers using the fused deposition modelling technology embedded in Moodle

The second part of the Moodle course digitally maps the laboratory. The process starts with the mandatory general safety instructions, including the machine manuals and the specific safety data sheets. This part of the course is divided into subgroups: a general overview, operating instructions, safety instructions, safety data sheets for the different types of machines (e.g., 3D printer, laser cutter, and milling machine), and links to the required software. The level of detail increases as students dive deeper into each topic. For each machine, the first level provides a short data sheet with technical data, the most important safety instructions and possible applications. The next level provides access to video material (Fig. 2), which depicts all the instructions for the individual machines and devices, regardless of the time of day or the laboratory staff's office hours.

The general safety instructions for the creative prototyping lab and the instructions for each machine and piece of equipment (including hand tools such as saws, pliers, and knives) were previously done in person, written down on a sheet, and placed in a binder for each student or small group of students. This was a very important but time-consuming task. As part of the digitization process, we mapped the general safety instruction as an e-learning unit, for which students receive a certificate upon completion. This is then archived digitally, so that the previous paper-based form of documentation has been replaced. The safety instructions for the individual machines and devices are carried out via e-learning and a final test, for which the students receive a certificate. A score of 100% must be achieved on all safety instruction tests to ensure a high level of understanding. Figure 3 shows a screenshot of the general safety instruction test.

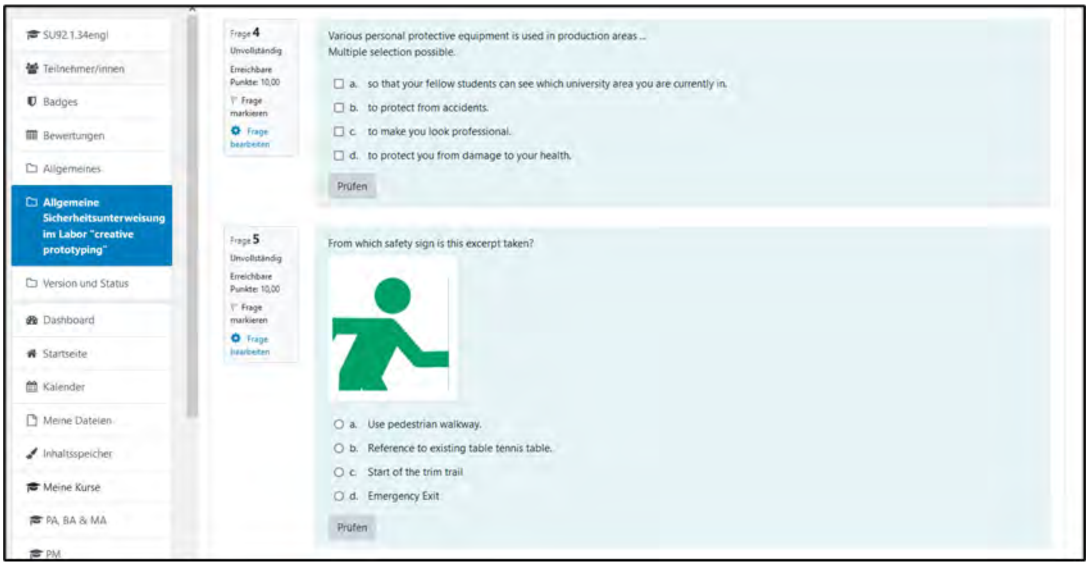

Fig. 3. Part of the test on general safety instructions

The digital approach for the safety instruction part is superior to the previous analog way in virtually all respects. The time flexibility (as with machine instruction) is the biggest advantage. Understanding of hazards and processes is also improved by the combination of self-study and mandatory final test. The digitized lab is rounded out by an appointment calendar (on Moodle) that can be used to book machines and office hours with the professor or lab staff, where general questions or problems from feedback loops can then be addressed. When a face to face meeting is not necessary the students can contact the staff via vide call and gain additional flexibility within their time schedule.

3 THE CHALLENGE OF TRANSFERRING THE LAB TO THE DIGITAL WORLD

Various difficulties and obstacles arose during the implementation of the project. First and foremost, the professor and staff had to invest a great deal of time in preparing for the project. Digitizing a lab that normally operates exclusively in the analog world and only with staff present required discrete solutions to a variety of small problems. The effort required to create the videos, images, and audio for synchronization with Moodle was significant. The time required exceeded the preparation time for an analog course by far. However, it was a one-time effort, and subsequent maintenance and updating of the course will be less time-consuming than for the analog version.

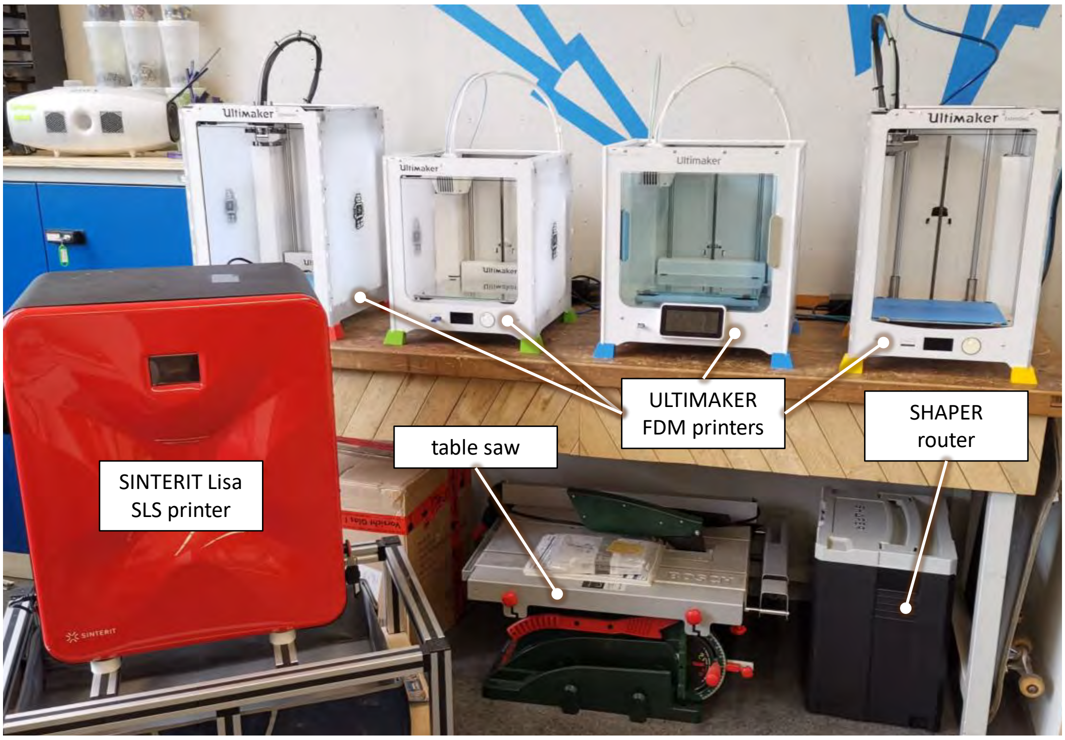

Fig. 4. Resources and machinery in the “creative prototyping” lab (3D printing corner)

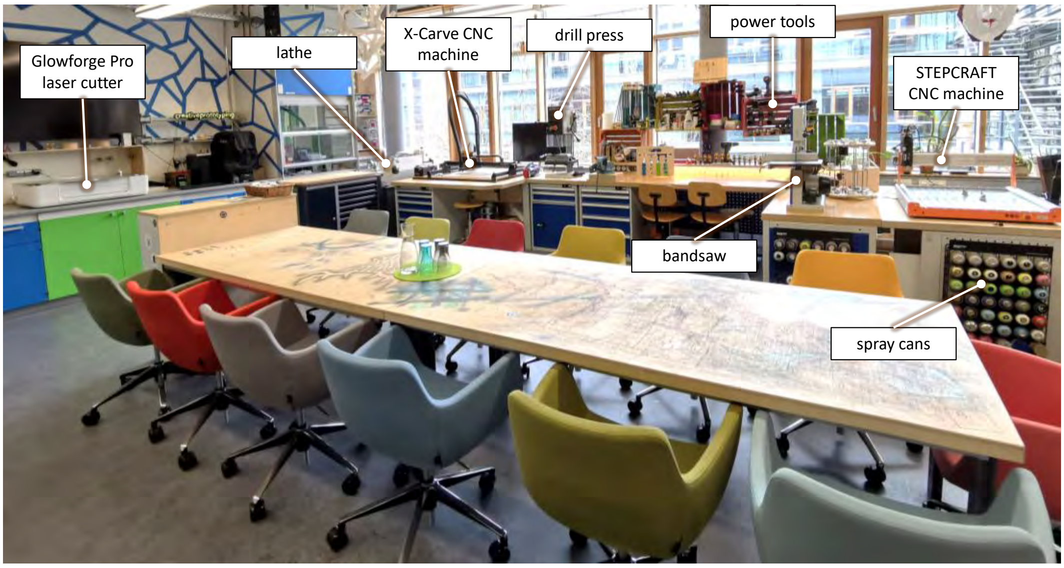

Fig. 5. Resources and machinery in the “creative prototyping” lab (view from right corner)

Another problem was presented by the different interfaces between the laboratory machines and devices (Fig. 4 and Fig. 5). Since the latter are designed more for hobbyists and enthusiasts and there are no common interfaces for devices and machines for industrial use, direct communication is hardly possible. Although each fabrication machine uses a g-code-based controller and some are equipped with browser-based software, each type of device has to be prepared separately, and this also applies even when a 3D printer is replaced with another model from the same manufacturer. The acquisition of a uniform system for managing, controlling and supplying all devices with data or devices with industry-standard interfaces was out of question for financial reasons.

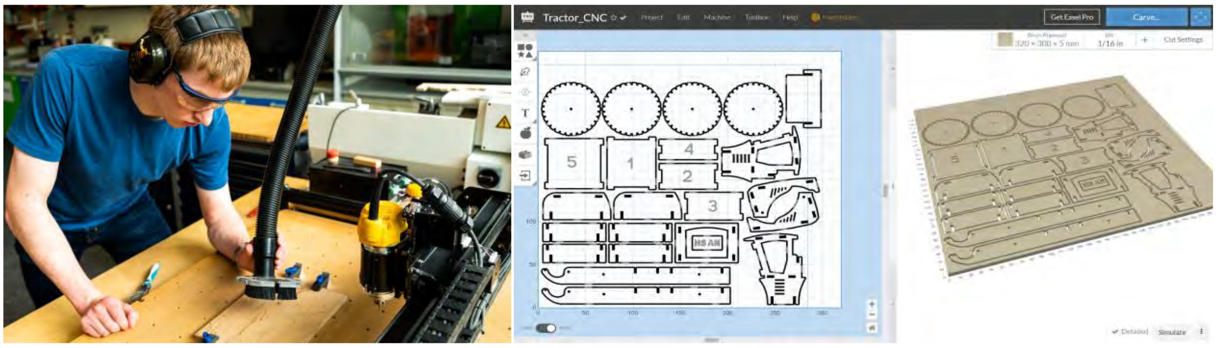

Fig. 6. Student working with the CNC carving machine (left) and view of the browser-based software for the milling machine (right)

To solve these problems, we first set up a network to control the 3D printers and the laser cutter. These devices either have built-in Wi-Fi capabilities (e.g., the Glowforge laser cutter) or can be connected via an Ethernet interface (e.g., the Ultimaker 3D printers series 3 and higher). Students working in the lab can connect to the network and access the devices virtually from their own computers wich reduces necessary data transfers to the computers of the staff and the network of the university. The browser-based milling software (Fig. 6) [7] and laser cutter can be prepared regardless of location; only the final fabrication must be done in person. The software is linked and easily accessible within the Moodle course. The course is supplemented by links to online CAD [8] and slicing software for the FDM 3D printers, giving students even more flexibility. Unfortunately, these browser-based tools cannot be embedded as plugins in Moodle. The current version of the creative prototyping lab's digital twin jumps from digital solutions within the lab and university infrastructure to external infrastructure. This will be the subject of further research.

External access to the devices or the lab itself is also not entirely straightforward. Although there is an internal laboratory network, it is not connected to the public Internet and cannot be accessed from outside for security reasons. Therefore, a fully automated and globally accessible solution is needed. Unfortunately, this is not financially feasible for the university; in addition, time is a limiting factor, as the solution would have to be customized. As a compromise, the submission feature of the Moodle platform is currently being used. After the student submits their double-checked production data, a staff member transfers it to the lab's ecosystem and performs a final check before prototype parts are produced. A centralized means of sharing and storing production data outside of the lab's ecosystem that eliminates the need for manual work by the lab staff is in the works.

4 STUDENT AND STAFF FEEDBACK

The students feedback on the summer semester 2022 led to the conclusion that access to the lab (e.g., in terms of timeslots) and the overall experience of it had to be improved upon. In 2023 with the next round of the course on project-based product design, the evaluation of the changes to the lab ‘creative prototyping’ and the students’ interaction with the new digital learning environment twin will be evaluated. The results of the evaluation are the base for iterative changes to the digital learning environment twin and the lab. This cycle of feedback and modifications to the course will be used for at least the 4 following years to refine the students' learning experience.

The lab staff and course lecturers mention a decreased and more flexible workload. This is a direct result of the temporally non constraining conditions provided by the digital lab twin. The initial investment of time and work to set up the digital lab twin is already paying off.

5 CONCLUSIONS AND OUTLOOK

The digitization of the lab and the use of the digital lab twin in teaching have proven to be a viable concept with a high potential. In conclusion, the future use of the new setup with iterative improvements promises a great learning experience for students. It helps to gather agility within the engineering education. The increased understanding of hazards and processes within the lab has improved through the combination of self-study and mandatory testing. To prevent a fallback into old (more analogue) patterns, the new digital offerings must be used consistently. This involves all parties to maintain discipline.

In the future the lab 'creative prototyping' shall be linked analogue and digitally with an also digitized neighbouring lab to create an open-access maker space for students from all faculties and people from the public, to realize their project ideas. With the lessons learned from the evaluation of multiple rounds of the course on project-based product design, this new maker space shall offer new levels of accessibility and usability 24/7. However, the focus of usability stays on the students.

For the future the question on interaction between students has to be asked. How differs the student interaction within the digital environment from the high level of peer interaction in physical maker spaces? Does the digital twin reduce the peer interaction by significant means?

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REFLECTIONS ON ENGINEERING HOME LAB KIT USE IN A POST PANDEMIC ENVIRONMENT

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ABSTRACT

Laboratory experience in engineering significantly impacts upon how students view their courses. Whilst there may be nostalgic memories of what this offered the educator on their own route through further education, it is often far from the modern

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reality: time bound, pre-configured, minimal student agency over input variables, and something of a data grab and dash.

Home Lab Kits (HLK), one of the innovations whose use was accelerated as a COVID-19 mitigation, have provided some long-term improvements in the educational lab experience of undergraduate engineering students in the School Civil, Aerospace, and Mechanical Engineering (CAME) at the University of Bristol. The HLKs provide an experience that allows for: independent play and exploration, development of extracurricular experimentation, and time to problem solve and learn from mistakes. This paper reports on both the educator experience and the student voice for a large common team-taught engineering lab unit delivered to ~550 students.

Students report that they have “used [HLKs] for a number of [their] own projects”, that they are a “great way to get people excited about what we're actually learning about” and “made [them] feel like an engineer”.

Whilst HLKs provide for less prescriptive laboratory classes, they can also lead to students being worried about less structured problem solving. However, combined with well-designed taught elements, they can produce an exciting buzz of real-time investigation and collaboration with students.

1 INTRODUCTION

1.1 Background

As is becoming the catchphrase of the decade, the Higher Education (HE) sector is going through a time of unprecedented turmoil and change with COVID 19 and the rise of freely / cheaply available generative artificial intelligence language engines potentially revolutionising the HE environment . Whilst these changes may have accelerated moves towards digital learning, the laboratory experience and practice of engineering hands-on-skills is difficult to replicate in a simulated environment. For instance, whilst the use of pre- and post-tests and virtual lab activities have resulted in more frequent engagement with the learning materials and no detriment to assessment scores, virtual labs do not necessarily help embed curiosity .

Home Lab Kits allow students to carry out practical work in their own homes, and became increasingly popular with both staff and students during the COVID-19 pandemic . A selection of simple parts and equipment is delivered to students, who are then required to use the kit to complete an activity at home, similar to one they may have previously completed on campus. This allows learning outcomes to be satisfied, practical skills to be developed, as well as encouraging a more investigative and open-ended approach than traditional ‘black box’ on campus experiments.

1.2 CAME School Home Lab Kits

The common first-year laboratory unit known as Engineering by Investigation (EbI), delivers a laboratory experience to ~550 students per year. The unit is common to Aerospace, Civil, and Mechanical Engineering, as well as Engineering Design courses, and provides a Home Lab Kit (HLK) to each student. Whilst faculty support was initially driven by the need to facilitate learning in COVID-19 restricted context, it had been the teaching team’s desire to move in this direction for some time. A key concern of the teaching team was that laboratory offerings were evolving into a somewhat turnkey experience as a result of time and space constraints. The HLKs were designed to facilitate exploration, where problems with a degree of open-endedness could be proposed for students to solve and explore using techniques taught in the accompanying lecture series, while still satisfying the learning outcomes associated with practical activities. The contents of these kits are extensive, and an example is illustrated in Fig. 1.

Fig. 1. 2022-23 HLK

A summary of the contents is provided below:

- Selection of mixed resistors, capacitors, and diodes
- Various Integrated Circuits (ICs) including 555 timers, op-amps, logic gates, voltage regulator
- LEDs
- Raspberry Pi Pico microcontroller
- Breadboard
- Jumper wires and wire cutters
- Multimeter
- Drawing equipment
- Miscellaneous experimental equipment: strain gauged aluminium, measuring cylinders, syringes, safety glasses, measuring tape, steel rule, vernier callipers (analogue), to name a few.

The total number of different components was ~88 with a total part count of 260 items. Whilst certain items were selected to facilitate pre-identified laboratory tasks a large number were also incorporated for students' personal projects and future use throughout the degree programme. Indeed, two further second-year labs have been facilitated by the additional components in the kits.

1.3 Learning outcomes and lab activities

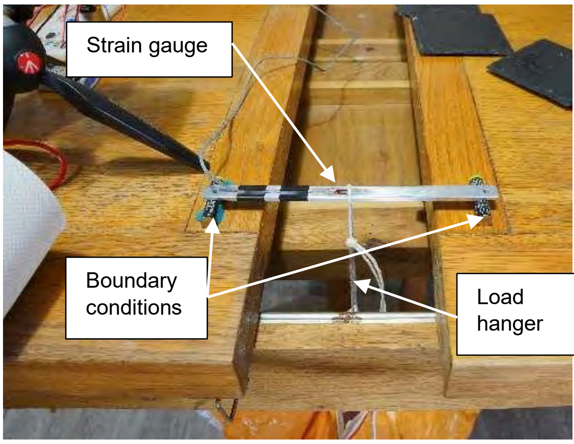
This section highlights some of the key laboratories that are facilitated with the HLKs in the context of the intended learning outcomes of the unit. Whilst the full Intended

Learning Outcomes (ILOs) are publicly available they can broadly be categorised into 4 core elements:

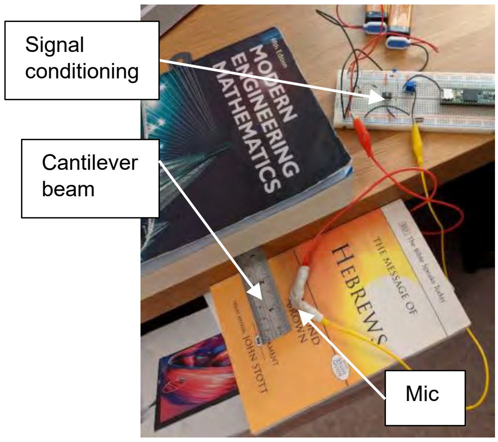
- Engage in required Health and Safety processes such as risk assessments.
- Develop Python coding skills to evaluate numerical data and present output appropriately.
- Use electronic principles to develop basic signal conditioning, acquire signals, select appropriate sensors recognising the impact on error, accuracy, and resolution.
- Structure a written report, including appropriate use of tables and figures, to present a coherent story.

There are four at-home labs:

1. Thermodynamics lab (formative) – evaluate the specific heat capacity of water (using a stopwatch and a measuring cylinder) and the performance of your kettle.
2. Simple bending lab (formative) – using basic hand tools (vernier callipers, steel rule, tape measure) evaluate the empirical results collected against that of Bernoulli-Euler Beam Theory.
3. Strain lab (formative) – using a provided flat strain-gauged aluminium bar, build a Wheatstone bridge with associated amplifier, implement a shunt calibration, and evaluate the empirical strain against that predicted by analytical theory. Student example shown in Fig. 2 (a)
4. Dynamics lab (summative) – using the microcontroller to acquire data, amplify a microphone output to measure the frequency content of a cantilever beam (steel rule). With the observed fundamental frequency, estimate the Young's Modulus of the material. Student example shown in Fig. 2 (b)



(a)



(b)

Fig. 2. Examples from student reports, (a) Strain lab, (b) Dynamics lab

Additionally, there is one on campus lab that provides access to research laboratory equipment.

1.4 Scope of this practice paper

While Home Lab Kits were commonly provided during the pandemic, there is little literature around their continued use post-pandemic now that many institutions have returned to a business-as-usual approach to labs. In this paper, we aim to report our experience of embedding use of home lab kits into a 1st year practical skills unit as a potential new best practice. We report student experiences of using the kits, as well as staff reflections, and hope that by sharing our experiences others will be inspired to introduce or continue using home lab kits.

2 METHODOLOGY

The evaluation of the HLK intervention has been two-fold. Firstly, a broad overview of the cohort experience was collected through a survey of students enrolled in the unit in 2022/23 (ethics approval was given by the Faculty of Engineering Research Ethics Committee at the University of Bristol – ref. 14061). Secondly, the teaching team (the authors) have reflected on the use of HLKs since 2020/21 through informal discussions.

A survey was designed to collect user feedback from students, and included questions on both the practical experience of using the HLKs (Questions 1-3,9) and the logistics of accessing support while using them (Questions 4-8). Questions were also included to provided general feedback on user experience (Questions 10-12).

The delivery of these kits to cohorts of ~550 students represents a substantial financial investment at approximately £200 per kit, so their use and adoption are crucial to ensuring good value and return. The main survey questions are shown in Table 1 (the participant consent questions have been omitted from this table).

Table 1. Survey questions

#	Question text	Response options
1	The Home Laboratory Kit was easy to use?	Five-point scale: strongly disagree, disagree, neutral, agree, strongly agree
2	The kit helped me engage with the content of the units for which it was designed?	
3	The kits have helped me in other units and/or my own projects?	
4	The supporting material (e.g. videos/manuals) was helpful	
5	I was able to access the Laboratory Kit BB page through the QR Code	
6	The Inventory of Parts on Blackboard was helpful	
7	Did any components break whilst using the Home Laboratory Kit?	Free text
8	Are there components included in the kit that are not needed?	
9	Are there any components that should be added?	
10	What did you like the most about your kit?	
11	What did you like the least?	
12	Do you have any other suggestions or comments on how we could improve the Home Laboratory Kit?	

3 RESULTS AND ANALYSIS

3.1 Five-point scale responses

The survey had 90 responses from the student population, ~16% of the total cohort. Whilst this was lower than hoped as a proportion of students, the total number of responses was still high enough to draw some useful conclusions. The five-point scale output is shown in Fig. 3, with a broadly positive outcome across all questions.

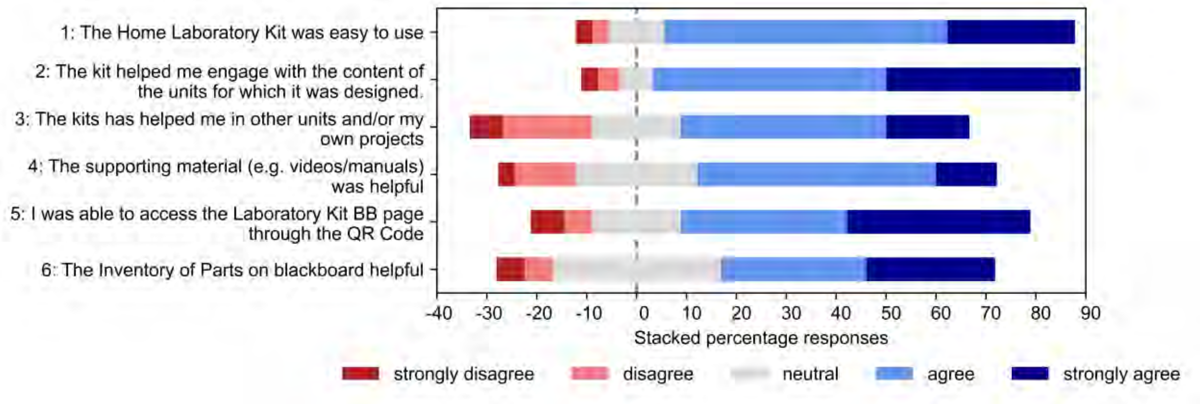


Fig. 3. Summary of Likert scale responses

The survey results indicate that the kits perform exceptionally well in fulfilling their original design purpose of supporting the core unit. Questions 1 and 2 show 82% (93% inc. neutral) and 86% (92% inc neutral) response rate towards agree and strongly agree for the kits being ‘easy to use’ and ‘helped me engage with the content of the units for which it was designed’ respectfully. This provides good evidence that the kits were performing their intended task well. With the other questions less narrowly focused on the kit’s ability to perform its intended purpose the breadth of response increases. Question 3, for instance, is extremely dependent on the student's own interests – students who identify as ‘hobbyists’ are more likely to use the HLK contents in their own personal projects, whereas students who are less confident or interested may be less likely to explore using the HLKs for other purposes. However, even in this category 58% of respondents suggested it was helpful outside of the immediate unit. While on-campus labs can have some benefits, including exposure to research/industry-grade equipment, , they are also usually limited in scope to allow a large number of students to complete the lab during specific timetabled sessions. The positive responses to Q3 is suggests that the value of the kits extends beyond the planned activities which is harder to achieve with a conventional lab approach.

3.2 Free text responses

A large number of the free text responses from the students were associated with specifics of components (questions 8 and 9) which would not add to the discourse of this paper; thus, these have not been included, but have been used by the teaching team while reviewing the HLK contents for 2023/24. Responses to the other questions have been categorised by theme within each question, and the categories and number of responses are shown in Table 2.

Table 2. Categorisation of free text responses from N=90. Note that the total number of responses for each question does not necessarily sum to 90 as the questions were not compulsory, so some respondents did not answer all questions.

Q7: Did any components break whilst using the Home Laboratory Kit?	
Coding category	**Count**
Strain gauges	12
LEDs	6

Miscellaneous	6
Q10: What did you like the most about your kit?	
Coding category	**Count**
General positive comments	35
Use for own projects / creativity / at home	22
Variety of components	15
Tools supplied	13
Portability	11
Raspberry Pico Pi	9
Q11: What did you like the least?	
Coding category	**Count**
Box size	17
Variety of components	9
Difficulty repacking	6
Miscellaneous	23
Q12: Do you have any other suggestions or comments on how we could improve the Home Laboratory Kit?	
Coding category	**Count**
Provide smaller sub containers for carrying parts to university	5
Label individual components	5
Provide printed components list not web QR code	4
Make the kit smaller	4
Would like a stronger box	2
Would prefer traditional on campus labs	2

A key outcome from Q7 was the relatively high number of failures of the strain-gauged aluminium bars (13% of respondents reported this problem) and LEDs (7%). The strain-gauged bars were required for one of the formative labs, and the LEDs were used during the first circuit building taught session. Although students have reported problems with these components, teachers noticed that most often failures were due to user error, typically a fault in the circuit either leading to the LED being over-powered, or the strain gauge not being powered at all or being incorrectly amplified. This has reinforced the need for the teaching team to provide clear and appropriately pitched support for novices when building and troubleshooting circuits. Troubleshooting circuits has been observed to fundamentally challenge students taking the unit, where the tacit skill of methodical fault finding is lacking, and changes to the way this is taught are being incorporated into the unit for 2023/24.

The responses to Q10 help to unpack some of the reasons for the previous positive feedback in the five-point scale responses. While 39% of responses contained generic positive comments, 24% specifically mentioned the opportunities the kits provided for extracurricular activities associated with creativity, as well as the reduced time constraints when working at home. There were further tacit benefits, as illustrated by students reporting that "it made [them] feel like an engineer," "Being able to conduct real experiments at home," "I've used it for a number of my own projects so far and can see this continuing and being added to by myself," and "I have [components] that I can keep once lectures finish so I can continue to make things." These responses hint at the transformative change that this approach has compared to the previous one. While in two cases, students directly referenced a desire for more on-campus labs, there was no evidence of a cohort-wide desire for a significant change to the HLK approach. In fact, many of the responses referenced benefits from the HLKs which would be unachievable with traditional laboratories, supporting the decision to continue using HLKs post-pandemic.

4 AUTHOR REFLECTIONS

The authors of this paper are all involved in designing and delivering the HLK activities reported in this paper, and have drawn together their reflections on the benefits and disadvantages of HLK usage.

Amidst the complexities of today's Higher Education sector, the kits have provided a highly scalable solution to delivering engineering labs that can be easily sequenced with other taught content. For instance, due to timetabling constraints, on campus labs used to be delivered either significantly before or after a science topic was taught. HLKs are not impacted by these constraints, and have provided new opportunities to deliver laboratory experiences at appropriate timings compared to the underpinning engineering science taught elsewhere.

An additional challenge of home labs is the changing prior experience of our intake. While previous generations were perhaps more likely to have spent time disassembling and repairing engineering artefacts like radios, bikes, cars, and desktop PCs, today's society frequently uses sealed devices making this tinkering more difficult. Anecdotally, staff delivering labs have noticed a decrease in both confidence and ability of students undertaking practical tasks, leaving our students potentially less comfortable with aspects of home exploration, but potentially in more need of it. This discomfort was particularly evident when using early iterations of the HLKs in a fully online delivery mode. Adding in-person group activities using HLKs as part of the taught sessions on the unit seems to have reduced this problem. Careful design of home labs to gradually increase the complexity of activities throughout the year has also allowed students to familiarise themselves with each level before moving on to the next.

One further concern of the teaching team was the inability of HLKs to expose students to industry standard equipment. To combat this issue, one ‘traditional’ on campus lab is offered, with a focus on students predicting and estimating their results before conducting the experiment. The focus on prediction is to ensure that the key skill of critically evaluating data in real time during collection is practiced. This encourages students to consider the quality of data collected before leaving the laboratory, whereas when using HLKs students are not constrained in this way and often repeat an experiment excessively without considering whether their results are sensible.

5 CONCLUSIONS

This paper reflects on the ongoing use of HLKs in a 1st year lab unit. It provides student centred evidence that the use of HLKs for the development of experimental skills and curiosity has had a positive impact. The vast majority of respondents (82

%) suggested the HLKs were easy to use suggesting the kits were appropriately pitched for 1st years. In general, HLKs have been well received, and students are not demanding a return to the previous days of solely providing on campus labs. Staff reflections also confirm this positive impact, especially when considering the demands of providing a scalable solution for practical activities. However, careful design of supportive in-person activities and scaffolded at-home activities are required to ensure students are not overwhelmed when developing their practical skills in isolation.

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A WAY TO GET STUDENTS TO CONSIDER ETHICS AND SUSTAINABILITY IN IOT PROJECTS

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ABSTRACT

Sustainability and ethical topics can be embedded and assessed in existing technical courses within an engineering curriculum. This article describes how we integrated a reflection on the importance of ethical and environmental aspects of connected objects through team-based project learning with computer science students in the second semester of their Bachelor degree. Small groups of three were given different projects, in which they had to implement the technical concepts learned in class using both virtual and physical components. The projects followed realistic scenarios chosen at random, each of them using a specific set of sensors and built to question either personal data collection, ethics or sustainability issues. At the end of the project, each group had to demonstrate their connected object proof of

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concept during an oral presentation and to prepare a group written report. The project is one of the continuous assessment elements of this module.

After mapping the different projects and their associated sustainability and ethical topics, we present how the initial assessment grid of the project evolved into a three-fold version. The final grid explicitly invites students to explore sustainability and ethical aspects in their reports, in addition to the technical aspects, and includes a peer review section. Examining to what extent students developed an original reflection on sustainability and ethical aspects of their projects, we finally suggest possible extensions and improvements, and list some context elements that are to facilitate future implementations.

1 INTRODUCTION

1.1 Ethical challenges of Internet of Things in engineering education

The Internet of Things (IoT) is a network of connected things, with applications in all areas of our societies, from personal to professional life. New IDEs (integrated development environment) offer easy access to IoT development for developers, teachers and students. Being key elements of *Industry 4.0* (Roblek et al., 2016), IoT are the result of a collision between different technologies such as wifi, 5G, and powerful microcontrollers integrating security libraries, all in a limited space. Invading our space, continuously exchanging data, the rapid growth of IoT is associated with major data-related ethical issues (Karale, 2021). Data collection related to the use of IoTs raises many questions in relation to the seven principles of ethical decision-making in engineering - honesty, integrity, keeping promises, loyalty, fairness, respect for others, responsible citizenship, striving for excellence and accountability (Josephson,2013).

Mapping ethical practices of European hardware and software developers, the VIRT-EU project found “IoT developers lack practical guidance on the ethical and social issues of data use” (Powel et al., 2017). Guidelines from the EUR-ACE® labelling agency expect students to graduate with an understanding of the societal and ethical impacts of engineering. Mixed-mode approaches, combining traditional taught courses and project-based components (Mills and Treagust, 2003) are recognized as being efficient for teaching technical knowledge and transversal skills together. Byrne introduced macro ethics objectives in a 1st year Bachelor module dedicated to process and chemical engineering, showing that students were able to engage in a macro ethical sustainability informed approach (Byrne, 2012). A recommendation (Isaac et al, 2023) is to implement contextualized teaching and assessment of ethical topics within technical courses in the engineering curriculum, in order to avoid students seeing ethical issues as peripheral.

1.2 Context elements

The IG Bachelor of Geneva School of Management (HEG), from Western Switzerland University of Applied Sciences and Arts (HES-SO) prepares students from various backgrounds for working in software engineering and information systems. Multidisciplinary, the Bachelor study plans also include training in business, communication and management. Half of students come from pre-university diploma with specialization in economics, the other half from professional diploma.

Having students work on IoT places them at the intersection of various technologies and allows the introduction of multiple interdependent concepts. In 2019, this led the Bachelor teaching team to test two labs using Arduino development WiFi boards within the 14 labs of the WiFi course for second-year Bachelor students.

The study plans evolved in 2020, with the idea of adapting the contents to the technical evolutions and to offer more opportunities for learning through projects. As the 2019 experimentation was very well received by the students, a new module specifically dedicated to IoT was introduced in 2020 as part of the new 1st year Bachelor study plan.

2 THE EVOLUTION OF THE IOT MODULE

In the Cultural Historical Activity Theory framework, teaching is considered a professional activity (Engestrom, 2000). Teachers continuously improve their professional knowledge (Grangeat and Hudson, 2015), and adapt their practices 1) through short term regulation loops in reaction to the immediate classroom feedback, and also 2) through long regulation loops that result from reflections that the teacher has on the effects of her or his teaching practices (Jameau and Boilevin, 2015).

Since its first implementation in autumn semester 2020, the IoT module has gone through four iterations and evolutions, as shown on the circles of Figure 1. Each evolution results from students' written feedback and/or teacher analysis of final presentations, as summarized under each circle.

Fig.1. In the circles, short descriptions of four iterations of the IoT module – The lines below summarize the feedback from students, the quality of students' final presentations and of the level of their ethical reflexion

The regulation loops from one iteration to the next are described below, in order to analyse how working on ethical issues enriched the module learning outcomes.

2.1 First iteration in 2020-21

In 2020, the module was a project-based module for the first year Bachelor students. Despite the Covid situation, labs and lectures were given on site. The module took place in the second semester of the Bachelor.

2.1.1 Objectives and activities

The main goal was that students understand the technical big picture of networks and master elements such as programming and cross-compiling software, physical sensor connections, networking, and wireless transmission.

Students were told that the course assessment included a project at the very beginning. The course began with a slide (Figure 1) showing the elements and the interactions that students needed to understand and manage to implement their project at the end of the module.

The progression of the module began with one-third of content on networks, followed by two-thirds of IoT-specific content. Every week, the lecture and lab focused on a specific networking element. In week 9, students received the hardware and their individual project subjects. Students were provided with a rubric assessment grid, covering technical knowledge and presenting skills.

2.1.2 Students' feedback and presentations

At the end of the first iteration, teachers and teaching assistants observed that the students complained about having difficulties managing the project schedule. It was true that the project ended the semester but its overall perception by the students was late, its implementation was delayed and then truncated by the end of semester deadline. In addition, because the students were not used to having the freedom to choose the elements of their project, they encountered difficulties making choices. They tended to be overly ambitious, were slow to get started, and scaled back their projects at the last minute.

Teachers found that the rubric assessment grid was followed step by step by the students that relied on its criteria to build their project. Student feedback showed that they appreciated the fact that the evaluation was strictly in accordance with the rubrics.

During the presentations, teachers also observed that the topics of ethics in the IoT were not at all addressed in the students' projects and that the students' responses to questions about ethics showed very little awareness of potential problems, although some points were brought up in class.

2.2 Second iteration 2021-22

2.2.1 New activity order and concept maps

In 2021, the activity order was modified in order to address the points that are described above, as follows:

- The module started with the IoT part, for students to have more time for the project. Having access to the hardware after week 7, students had the opportunity to elaborate their project for 5 weeks before the final presentation.
- The contents covered by each lecture and labs were highlighted step by step on a concept map, in order to help students gain a global view of the connections between the concepts seen in lectures and labs accompanying the project.
- More emphasis was put on ethics during lectures

- More powerful hardware was also provided, in order to prevent technical issues and provide greater diversity in projects.

During the semester labs, teachers observed that, despite working on separate individual projects, students tend to help each other to solve technical problems. The teachers encouraged them to solve problems by discussing.

2.2.2 Project outcomes

The results of the implemented changes were as follows:

- The quality of students' presentations increased, including original uses of sensors and devices. Some students expanded the scope of their projects, by using additional virtual sensors and networks. However, others had more difficulties and only adapted directly the examples provided in labs.
- Whereas ethical elements were included in lectures, most of the students' answers to the questions about ethical aspects remained poor in the final presentation of their projects. For instance, they did not appreciate the stakes of permanently geolocating people.

2.3 Autumn 2022

2.3.1 From individual to group projects and inducing ethical reflection "by design"

In autumn semester 2022, the project format evolved from individual projects to group projects, with objectives of 1) better preparing students for groupwork in their undergraduate project module, 2) encouraging peer-to-peer support as previously observed, and 3) expanding the scope of projects.

In order to emphasize sustainability and ethics, the project topics were built in order to generate this reflection "by design". To achieve this, all projects involved at least (1) an infrared sensor for detecting human presence (generating sensitive personal data), (2) a messaging broker (for data publication) and (3) a collective messaging broker (for data storage). This specific setting was to induce reflections on personal data storage and publication on distant servers, and also on the nature and choice of data to be shared or not.

Sustainability and ethical reflection rubrics were added to the rubric assessment grid. Students had to implement all available sensors in order to respond to the need of the clients (teachers), even if the clients' wishes raised ethical issues. Then, they had to identify and discuss the ethical and sustainability aspects that are at stake, in a specific part of the written report.

2.3.2 Students' ethical reflection

Table 1 shows the themes and a non-exhaustive list of ethical stakes. The issues that students identified in their written report are in third column.

Table 1. The themes of the projects (left column), associated with a non-exhaustive list of relevant ethical stakes (central column) – Stakes that were identified b students are in the right column.

Theme	Relevant ethical stakes	Stakes identified by students
Surveillance of elderly people using IoT for detecting falls	Personal data (presence sensor) Health data (fall information) Data protection Choosing the person(s) to alert in case of fall detection False positives cases	Data center Safety of people
Cab service management using embedded IoT	Tracking of empty/loaded vehicles Tracking of working hours/ control of breaks Customer follow-up with their location, with whom they are accompanied ...	Employee monitoring Relocation of servers Reduction of power consumption
Personalized weather information service using IoT for home measurements	Personal data related to the person's presence at home Person's opinion of the weather provides data on the person's perception/morale Regularity of use provides behavioral or psychological profile data Potential for resale of free weather information	Sustainability, resource depletion Safety of people Access to private network (Trojan horse)
Air quality data sharing service using IoT for home measurements	Presence of the person Air quality inside/outside the person's home (smoking, ventilation, ... resale of information to insurance companies or contractors related to buildings) A way to know the lifestyle of the person using this type of sensor	Address/presence General pattern of behavior in the neighborhood Safety Sustainability - limiting consumption

In their final written reports, students identified some of the ethical issues related to their projects.

They showed awareness of direct and indirect physical safety issues:

> *"a malfunctioning panic button can have serious consequences."*
>
> *"to know if a person is present or absent from his home, or to know in which room of the dwelling he is currently, if he is sleeping… etc. A way to determine which homes would be an ideal target for a burglary for example."*

They also perceived the risks linked to the storage of personal data and the related environmental issues of using cloud storage:

> *"storing sensitive information about employee movements or customer itineraries on servers located outside our territories could be problematic"*
>
> *"(risk of) making an attack via the connected object in the house"*
>
> *"sustainability: would it be reasonable to relocate our servers beyond our borders?"*

Two of them made a stand and disagreed with systematic monitoring of people:

> *"Monitoring the activity of individuals in their homes and accumulating data thanks to sensors, in order to ultimately transmit them / make them available to companies or states would lead to the disappearance of the last bits of intimacy that human beings still enjoy."*
>
> *"Employee monitoring is the first ethical issue that comes to mind (...) do not store this data beyond one working day (…) nevertheless the problem of real-time monitoring persists"*

Another tended to leave it to the legislator to decide:

> *"(ask) whether public health (the health of the elderly) is an important enough value to preserve to accept the risks raised above. This is a task for legislators (and an ethics commission, for example)."*

2.4 Spring 2023 - Introducing ethics in group work

In spring semester 2023, after experiencing a first round of group grading, and noting that ethics in group work should be explicitly addressed, teachers proposed to the students to add related criteria in the group evaluation. The objective was on the one hand to value the capacity to work in group, and on the other hand to modulate the mark between the members of the group in the cases where it proves to be necessary (for example in case of "freeloaders"), the teachers' perception being modulated by the self-evaluation provided by each student.

Seeking for rubrics for constructing a groupwork assessment grid, previous work of Roach et al. (Roach et al., 2017), offered interesting perspectives: aiming to scaffold teamwork skills, these authors analyzed rubrics written by students for the evaluation of group work, according to affective domains, and extracted 51 items that they grouped into 5 themes (*valuing, responding, organisation, internalization*, *receiving*).

Of the 51 items extracted by Roach et al, we rewrite 20. Teachers choose 2 rubrics to be mandatorily assessed, and students were asked to select 4 additional rubrics for peer group work assessment. To guide them in choosing rubrics, three levels of self-assessment were described. Table 2 shows examples of rubrics.

Table 2. For each theme, an example of rubric, associated to its three groupwork assessment levels – Inside brackets, the number of groups that chose the given rubric.

Themes	Rubrics	Insufficient	Sufficient	Very good
Valuing	Contributes to ideas (7)	Doesn't come up with technical ideas	Contributes some technical ideas	Provide many good ideas
Responding	Responds to communications (7)	Doesn't answer emails, doesn't express himself / herself	Is able to communicate with others	Is able to give effective feedbacks to others ideas or comments
Organisation	Completing assigned tasks (6)	Delays and / or submits incomplete tasks	Completes tasks more or less on time without impacting others	Always respects deadlines and submits complete tasks
Internalisation	Group motivation (6)	Stays strictly in his own bubble	Motivates others by sharing knowledge	Encourages, explains and supports others in acquiring skills
Receiving	Accepting of ideas (7)	Does not accept other people's ideas	Considers the ideas of others	Values the ideas of others and incorporates it

2.4.1 Students' choices

There were 19 groups of 3 students and 4 groups of 2 in the spring semester cohort, 23 groups in total. From the 23 groups, 5 groups were made by associating randomly the students that did not attend lectures. These 5 groups did not make rubric choices.

Below are the choices of the 18 remaining groups.

- Theme choices: *Valuing* is the most chosen theme, with 37.5% of selected rubrics. Then came themes *Responding*, *Receiving*, *Organisation* and *Internalisation* (19%, 18%, 15%, 10% respectively of the selected rubrics.
- Rubric choices: The most selected rubrics were the examples given in table 2. The rubrics "Contributes to ideas (*Valuing*)", "Responds to communications (*Responding*)" and "Accepting of ideas (*Receiving*)" were selected by 7 groups out of 18 (38%). The rubrics "Completing assigned tasks (*Organisation*) "and "Group motivation (*Internalisation*)" were selected by 6 groups out of 18 (33%).

3 DISCUSSION

3.1 About the current assessment grid

From 2020 to 2023, the assessment grid evolved. It always included 3 parts. In 2020, because of Covid, students were allowed to video record their demonstrations. Fig. 4 shows the evolution of the IoT module assessment grid.

The ethical reflection on IoT was an implicit objective of the module in 2020. After the first iteration, it became obvious to teachers that developing students' awareness of ethical issues related to IoT was an important goal. However, in 2021 the focus for assessment stayed on technical knowledge and scientific writing.

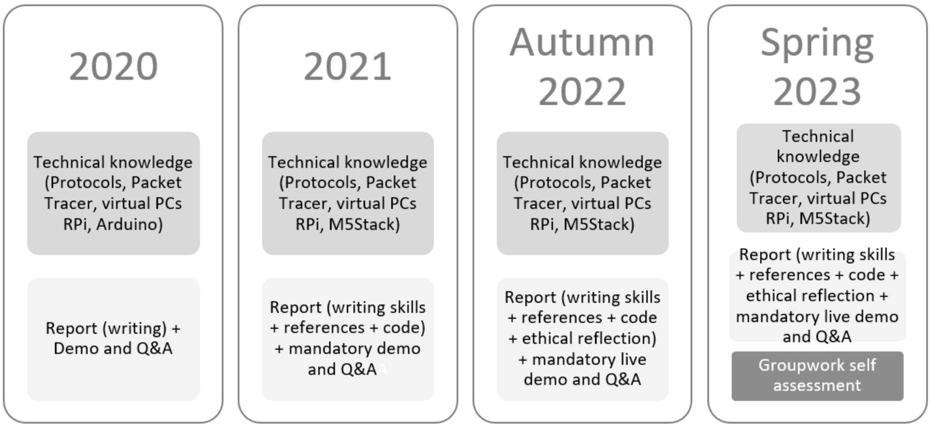

Fig. 4. Evolution of the IoT module assessment grid

Additional rubrics were added to the grid, in order to encourage students to be more rigorous in citing references and/or code they used for the project. In

2022, ethical reflection was integrated into the evaluation grid, with four level indicators (see Figure 5).

The current assessment grid is the result of the evolution of the module, reflecting the alignment of objectives, activities and assessment modalities (Biggs, 1996). It became a more accurate and useful tool for both teachers and students, at the cost of a more complex appearance.

Level	1	2	3	4
Reflection on ethics ans sustainability (in the written report)	Few elements provided, or general consideration not related to the project	Some elements are identified, the links with the project remain unclear	Correct reflection based on some elements related to the project	Complete and in-depth reflection directly related to the project

Fig. 5. Four level indicators of the ethical reflection rubric

3.2 About the sustainability of the module

Warren and Robinson (2018) suggested to consider courses through the lens of the *product life-cycle.* From this point of view, after 4 iterations, the IoT module may have reach its *maturity* level. Continuing to give the course, in its current format, should be the next step in its *life-cycle*.

At this stage, we feel it is important to raise the question of the sustainability of the module itself. In HEG, study plans are finalized by the teaching team and validated at the beginning of each academic year. The issue of faculty motivation for sustainability was identified by Thurer et al. (2018) as a key issue for integrating sustainability into engineering education, and programme directors expressed the need of faculty training to support them in integrating sustainability in their programmes (Leifler and Dahlin, 2020).

Since ethics was not embedded in the first iteration of the IOT module in 2020, potential changes in the composition of the teaching team entails a risk of losing the ethical component in the learning process for this module, insofar as the new team may not have the same sensitivity and motivation for ethics.

A module entitled “Ethics” does exist in HEG second year Bachelor study plans. However, we think important to contextualize the teaching of macro ethics, as suggested by Isaac et.al, and to give opportunity to first year students to rapidly develop an ethical reflection (Isaac et al, 2023). This leads us to recommend the setting of an educational policy that ensures keeping integration of ethics and sustainability within the IOT module.

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Screw Loose Toolbox:
24 metaphorical tools to foster the transfer of learning and critical analysis in the realm of technology, nature, society and the individual with democracy as the mediating instance.

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ABSTRACT

Blue Engineering is a student-driven course on the environmental and social responsibility of engineers. It has been developed by student initiatives at two German universities since 2010. By 2023, there are more than 15 courses at universities in Germany and in the Netherlands using the open source course design.
In assessing the learning outcomes of the participants, the need to promote the skill of transfer of learning of the students became clear. This practice paper presents the current approach: 24 metaphorical tools have been developed, each of which functions like a special lens, allowing to recognise certain patterns of action, discussion and collective decision-making that can be identified in many fields.
The *tools* are intended to point out shortcomings in our familiar environment and to offer starting points for the search for possible alternative ways of negotiating, with the normative goal of strengthening democratic process to balance interests.
This paper gives an overview of the competences addressed by the course, defines "transfer of learning" for the research, presents the developed tools and describes their current use in teaching and beyond.
Findings show that the Screw Loose Toolbox can succesfully be used to promote student discussion and reflection. As there are no generally agreed methods to measure transfer of learning and no quantitative results have been obtained.

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1 INTRODUCTION

1.1 The Blue Engineering Course

There is a broad consensus that, in addition to mastering engineering methods, addressing the role of engineers in the necessary transformation of human activity towards a just and sustainable form of economy should play an important role in the education of engineering students. In 2009, a student initiative was formed at TU Berlin to promote discussion of the social and environmental responsibilities of engineers in university teaching. Since then, the innovative approach of the Blue Engineering course has been twofold: a content focus on ethics and social and environmental responsibility, and a student-driven, peer-to-peer approach to teaching. The course design is based on *building blocks* – well-defined and described teaching/learning units that can be facilitated by studens– typically in a workshop atmosphere. The modules are not closely linked and do not need to be taught in any particular order. This allows variations in scope and time for different settings: new combinations of a subset of the available building blocks can easily be formed. In the course of a German semester of approximately thirteen weeks, a wide range of topics is covered.

The course, as taught at TU Berlin, follows a three-phase semester structure: in phase I, student tutors facilitate workshops – so-called *building blocks* – for usually around 100 participating students from a wide range of engineering programmes, with the majority from mechanical and industrial engineering programmes. In phase II, participants facilitate existing building blocks for their peers, before developing and testing new building blocks in phase III.

See Table 1 for an exemplary semester schedule of the course. In addition to facilitating an existing *building block* and designing a new one, students are required to keep a learning journal - a diary-style record of their learning journey.

The documentation of the *building blocks* and the entire course concept have been made available online as Open Educational Resources (OER). Today, courses exist at 15 universities in Germany and the Netherlands, and more than 1500 students have participated in a Blue Engineering course[2].

Table 1. Semester Schedule of the Blue Engineering Course at TU Berlin

Week	Phase	Topic / Building Block	Facilitated by
1	I	Introduction	Tutors
2	I	Plastics	Tutors
3	I	Topic & Group Finding	Tutors
4	I	Technology as Problem-Solver!?	Tutors
5	I	Responsibility and Ethical Codes	Tutors
6	I	The Productivist Worldview	Tutors
7	II	Work, Society and Labour Unions	Students
8	II	25 Questions by Max Frisch	Students
9	II	Automation vs. Good Jobs	Students
10	II	Gender, Diversity and Technology	Students
11	III	New Building Blocks	Students
12	III	New Building Blocks	Students
13	III	New Building Blocks	Students

[2] For more information on Blue Engineering and OER, visit http://blue-engineering.org

1.2 Learning objectives for the course

The project received funding from TU Berlin for innovation in higher education, and accompanying educational research was conducted by (Baier, 2018) from 2012 to 2018. As part of the design research, twelve competences were derived from the frameworks for Education for Sustainable Development and de Haans Gestaltungskompetenz, which the course was designed to address. See Table 2 for the competences. (Baier, 2018) verifies a significant increase in all twelve competencies defined for the course using a quantitative pre-post assessment of participants.

Table 2. Competences addressed by the Blue Engineering course design

Number	Learning Outcomes of the UNIVERSITY COURSE on Module Level
T1-BE	Students take perspectives, change points of view and gather diverse forms of knowledge (i.e. scientific, traditional, common sense) from various actors on the spatial and temporal effects of technology on individuals, society and nature.
T2-BE	Students anticipate spatial and temporal effects of technology on individuals, society and nature.
T3-BE	Students gain knowledge of the reciprocal relations between technology, individuals, nature and society through inter- and transdisciplinary approaches.
T4-BE	Students deal with incomplete and overly complex information on the reciprocal relations between technology, individuals, nature and society and the risks, dangers and uncertainties which arise from them.
C1-BE	Students cooperate for a democratic decision-making with regard to process, result and implementation
C2-BE	Students cope with dilemmas of decision-making when values and aims are conflicting.
C3-BE	Students participate in collective decision-making processes.
C4-BE	Students motivate oneself and others to democratise the reciprocal relations between technology, individuals, nature and society.
A1-BE	Students reflect principles which control the reciprocal relations of technology, individuals, nature and society.
A2-BE	Students identify the underlying values which shape the reciprocal relations of technology, nature, individuals and society and to use them to act morally.
A3-BE	Students plan independently and act autonomously according to one's own values.
A4-BE	Students support others who are disadvantaged due to the dominating design of the reciprocal relations between technology, individuals, nature and society.

1.3 Need for innovation

While the course design was successful in increasing students' competences, the tutoring team reported a recurring observation: students remembered facts and specific arguments from the topics covered, but struggled to recognise more abstract patterns present in different *building blocks*.

Many *building blocks* cover a topic by introducing a specific real-world problem. While gaining knowledge in specific areas is a learning objective, there are additional objectives in each unit that require some kind of abstraction.

For example, in the second week of the TU Berlin course, students role-play a television debate on the pros and cons of using bisphenol A (BPA) in the manufacture of plastics. Reflections on this debate in the learning journals often

remained focused on the details of the BPA debate, rather than linking the role-play debate to public debates about thresholds for potentially harmful substances or the role of science in societal decision-making, which had been introduced in the discussion following the role-play.
This observation was the starting point for the innovation process that eventually led to the creation of a set of metaphorical *tools* called the *Screw Loose Toolbox*. The guiding question throughout the process was: How can memories of underlying meanings or patterns be created that facilitate the recognition of these patterns in different settings and thus the transfer of learning?

2 TRANSFER OF LEARNING

A concise and universally accepted definition of transfer of learning could not be found. (Royer et al. 2005) provide an overview of different schools of thought that have contributed more precise, however not generally compatible definitions of the concept from the broad definition of transfer as "a situation where information learned at one point in time influences performance on information encountered at a later point in time".
(Wolfe et al 2005) promote the distinction between verbatim and gist similarity in explaining cognitive processes contributing to the transfer of learning. Their experiments extend the research on analogical reasoning by (Gentner and Holyoak 1997). They describe the process of analogical thinking as follows: a relevant analog is accessed in memory and then mapped to the target analog – the new situation to be assessed. "Systematic correspondences" between the two are identified, allowing "inferences to be made about the target by borrowing from the base." The results presented by (Wolfe et al 2005) suggest that this process of superimposing new impressions on known, more abstract concepts - gist-based similarity - plays a central role in learning processes that focus less on the reproduction of facts, such as the specific study results on the harmfulness of BPA, and more on the ability to recognise patterns and connections in different processes of a complex living world. This ability is referred to as transfer of learning for this paper.

3 SCREW LOOSE TOOLBOX

3.1 Background

The first step in promoting the memorisation of the more abstract concepts and patterns presented in the course was to make these concepts and patterns more visible to the students. The *Blue Thread* was introduced, a short presentation of new and already known concepts that could be found in a *building block*. Over time, the process of presenting the *Blue Thread* became more standardised: the concepts presented are called *tools*. The collection of *tools* is called the *Screw Loose Toolbox*.
One of the educational methods within the course is the *TINS_D constellation*, which can be used to assess human activities: the reciprocal relations between technology (T), individuals (I), nature (N) and society (S) are examined. As a normative setting, democracy (D) is placed at the centre as a mediating instance for negotiation processes between conflicting interrelations.
Engineering students as the target audience for the course bring to the classroom a focus on problem solving, often considering technical solutions first. However, Blue Engineering has its focus on a dialectic analysis of problems and possible solutions. The idea of *TINS_D* is rooted in Critical Theory and introduces additional dimensions to the analysis of problems and possible solutions. The emphasis on democracy

underlines the normative call for a democratisation of negotiation processes in conflict situations.

The concepts and patterns contained in the *tools* relate to such conflicting relationships. Each *tool* works like a lens that sharpens the contrast to make the encompassed concept easily recognisable, while blurring other possible interpretations of the object being assessed.

The *tools* make it possible to find connections between seemingly distant subjects and to uncover hidden patterns. These patterns are not presented as laws of nature or necessary sequences, but as recurring situations of values in tension. The *tools* are intended to point out deficiencies in our familiar environment and to offer starting points for the search for possible alternative ways of negotiating that strengthen democracy as a normative force for balancing interests.

One important property of each *tool* is a symbolic title: often based on real-world objects or figurative names the titles aim to evoke associations and emotions, thus making it easier to memorise and recognise. Additionally illustrations of each *tool* have been designed giving the *Screw Loose Toolbox* a common identity.

In terms of the theory of analogical reasoning presented above, each *tool* can be understood as a "relevant analog" that can be used to make inferences about the object under assessment - the "target analog" - and thus to generate new knowledge or interpretations of it.

3.2 Examples of the Developed Tools

Back to the building block on BPA in the manufacture of plastics: two *tools* are commonly introduced during the discussion following the role play: The *Slime of the Threshold Limit Value* and the *Poltergeist of the Neutrality of Science* (see Fig. 1).

Fig. 1. Poltergeist of the Neutrality of Science and Slime of the Treshold Limit Value

The Slime of the Threshold Limit Value emphasises the double faced nature of limit values: while a limit value seemingly creates a sharp contrast between harmful and non-harmful, legal and illegal, it is always the result of a negotiation process with typically conflicting stakeholders. New scientific insights as well as shifting societal paradigms lead to adjustments of the values, universally correct limit values don't exist. At best, a limit value represents a consensus of a community at a certain place and time. The disputes about the usage of BPA in the manufacture of plastic can be seen as an exemplary case of this relativity of limit values. The limit value for BPA in plastics has been adjusted multiple times over the last decades and the use of the substance has been banned for certain products. However, there is still no unity in the assessments of its harm.

The Poltergeist of the Neutrality of Science focuses on another pattern in the societal subsystem of science: while we as scientists strive for knowledge that is generally accepted and robust to changing contexts we remain highly influenced by our environment: its values, expectations and habitus. If we assess the scientific discourse around BPA in plastics using the lens of the Poltergeist, we recognise that the results of studies vary based on the background of the researchers, the sources of funding and the chosen system boundaries for the research.

3.3 List of all Screw Loose Tools

Beard of the Patriarchy – By the beard of prophets, the patriarchy also has a beard.

Cake for Simultaneously Eating and Keeping – Our dilemma is that we hate change and love it at the same time; what we really want is for things to remain the same but get better. (Sydney J. Harris)

End Credits of the Cat Video – The whole history takes part in the production so that the complete list of contributors is at least as long as the credits of 100 Hollywood movies. (Mathias Greffrath)

Clock that both Measures and Rules – The constraints of the Master become practical constraints and the external constraints turn into self-constraints. Technology not only conceals domination but also establishes and legitimises domination.

Linguistic Habit-Breaker – The language we use develops habits that affect the way we see, hear and think, subsequently shaping ourselves and our society. Once in a while, we have to break these habits to be able to see, hear and think in a new way.

Midas, the Societal King of Destruction – Only when the last tree has died, the last river has been poisoned and the last fish has been caught will we realise we cannot eat money.(Cree Proverb)

Technology's Vicious Cycle – Technology doesn't have to be evil to drive a vicious cycle.

Plastic Dinosaurs of Eternity – Dinosaurs and man, two species separated by 65 million years of evolution, have just been suddenly thrown back into the mix together. How can we possibly have the slightest idea what to expect? (Jurassic Park)

Fire Extinguisher Against the Inferno – It certainly does not hurt to go after a wildfire with one single fire extinguisher, but it won't do much good either.

Fireworks to My Delight and Your Suffering – A little bling-bling to make my own suffering more bearable has always ended up hurting everyone.

Poltergeist of the Neutrality of Science – The neutrality of science haunts heads, laboratories, societies and history. Over and over and time and time again.

Slime of the Threshold Limit Value – All things are poison, and nothing is without poison; only the dose ensures that a thing is not poisonous.   Paracelsus

Mark Twain's Hammer – When your only tool is a hammer, every problem becomes a nail. (Mark Twain)

Happy Meal of the Buy-Yourself-Happy – Buy, buy, buy - for a brief moment you feel alive! Yes, you definitely feel better! Now you are someone! Wait! Not so fast! The next moment you are no one again.
Jam Jar for the Individual – Allein machen sie dich ein. [Alone, they will put you in.] (Ton Steine Scherben)
Ladder of the Higher-Faster-Stronger – With the ladder of the Higher-Faster-Stronger, you can't go to heaven nor anywhere else, because its only goal is to go higher, faster, and further.
Steel Fist of the New Order – If you hit the table with your fist, don't be surprised about a broken table, a broken hand, and broken relationships.
Russian Residual-Risk Roulette – If persons expose themselves to a danger, they assume a risk, meaning that there is a certain probability that they will suffer damage as a result of the danger.
Yardstick of Democracy – The yardstick of democracy measures the capacity of whether all people can participate equally and freely in taking decisions.
Scissors of Inequality – Moreover, inequalities among people as a result of nature are not nearly as great as they become through education. (Johann Gottfried Herder)
Magic Socket of Abracadabra – Like a rabbit from a cylinder, electricity comes from the wall, water from the tap, schnitzel from the supermarket and and and ... with a snap it is gone again and disposed of in the best way.
Straitjacket of Nature – Any attempt to break the compulsion of nature by breaking nature only succumbs more deeply to that compulsion. That has been the trajectory of European civilization. (Adorno/Horkheimer)
TINS_D - Constellation – Technology, individuals, nature, society and democracy (TINS_D) repeatedly form powerful reciprocal relations that create something new and allow old ideals to fade away. These constellations must be both analysed and democratised.
Weight of Requirements – All humans are seen as equal before the law, but their respective needs and requirements carry varying weights in terms of shaping technology and society.

3.4 Use oft the Tools in Teaching

One or two *tools* are usually introduced in every course session and students are encouraged to use the *tools* for the reflection of their learning experience in the learning journal: they map a prescribed base analog to a prescribed target analog. To foster the transfer of learning, students should apply already introduced *tools* to other topics: in the second stage of the semester, small teams of students facilitate existing building blocks for their peers and propose one *tool* that can be used to asses the topic of the *building block*: they select a base analog from a set and map it to a given target analog. In the final part of the course, student teams design new *building blocks* and facilitate them for the other students. By choosing *tools* and topics together, starting points for interpretation can already be considered during the development of the *building blocks*. In this way, students introduce possible mappings between base and target analog and are motivated to introduce points of connection to other topics of the course. This underlines the shift in perspective of the peer-to-peer learning situation, as the students need to consider the stimulation of transfer of learning of their future participants in addition to conveying factual knowledge and problem analyses based on case studies.
In other Blue Engineering courses, further use of the *tools* has been made: students each choose a *tool*, which they then apply to a semester topic such as *nutrition*,

teaching at my university, or *artificial intelligence*. Over the semester, they develop a mapping of the tool to the application field. In a multi-stage review process, short texts (150–400 words each) are developed, refined and supported with sources. At the end of the course, the resulting application texts together with the *tools'* definitions are presented at the university as a small exhibition.

3.5 Exhibition "Rad ab, Schraube locker / Wheel off, short fuse"

Parallel to the use of the *tools* for teaching, the exhibition project "Wheel off, short fuse" was developed. For this purpose, the tools were applied to five subject areas, illustrations of the tools were created and everyday objects were placed in relation to the metaphorical tools as a tangible representation. The exhibition is designed as a touring exhibition and has so far been publicly exhibited at three locations in Germany. An accompanying catalogue with *tool* definitions and application texts has been published; a website presents illustrations and texts in German and English[3].

4 SUMMARY

4.1 Insights

24 *tools* have been defined and form the *Screw Loose Toolbox*. For more than five years these *tools* have been used for teaching at TU Berlin and other Blue Engineering courses. This timespan and the different course settings allow to present the following insights:

1. The *tools* offer various starting points for discussion during the course.
2. The symbolic titles and playful nature of the *tools* make meta-discussions about the reciprocal relations in the tension field of *TINS-D* easier.
3. The *tools* make it possible to see connections between seemingly disparate topics, and introduce a common theme into a course that, due to the peer-to-peer learning approach, covers a wide variety of topics and learning methods presented by constantly changing facilitators.
4. Students adopt the *tools* for the reflection of their learning experience in the learning journals. The share of texts that include parts of transfer of learning has been increased.
5. The use of the *tools* is not limited to the classroom. Exhibitions presenting the metaphorical tools, short texts mapping tools to topics of everyday life and real-world artefacts.

4.2 Limits

The following aspects were identified as being potentially detrimental to students' learning outcomes:

1. interpretations other than those presented by the tools could be suppressed. The presentation of the *Screw Loose Toolbox* and the shared visual identity could suggest a sense of completeness of the set.
2. the stimulus to search for base analogs might be reduced. Studies referred to in (Wolfe et al 2005) show inconsistent results when students are presented with possible base analogues as opposed to being stimulated to produce new analogues. However, doing one does not preclude the other.

The following limitations of the research were identified

1. The design of the *tools* did not follow a formalised process and the tools are not closely linked to the competences defined for the course. Rather, the tools were

[3] See http://screw-loose.org/

designed following a pragmatic approach: with regard to the desired learning outcomes of individual building blocks and possible links between them.
2. A quantitative analysis of the impact of the tools on students' learning outcomes was not carried out. The difficulties of measuring the ability to transfer are described in detail in (Schwartz et al 2005). According to the findings presented there, a robust quantitative assessment would require comparison groups, and even under laboratory conditions the ability to transfer remains difficult to measure.

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GENERATION Z AND THEIR USE OF LEARNING MANAGEMENT SYSTEM IN PROGRAMMING

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ABSTRACT

Generation Z students have grown up with ICT (information and communication technology) and are therefore used to being online more or less simultaneously on different types of media. Universities have different kinds of Learning Management Systems (LMS) with different possibilities for engagement. In the Electrical Engineering B. Eng. program at the Technical University of Denmark (DTU) we use a system called Learn. It has features for setting up individual study plans as well as common plans. Features such as surveys, quizzes, peer reviews are built in. We are interested in the students' use of the LMS, their engagement and the relation to their achievement in the examination. The research questions we would like to answer are: How much do the students use Learn? What kind of materials do the students prefer? Is there any correlation between the use of materials on Learn and the grade? Is there any correlation between the score in quizzes and the grade? In this paper, we would like to describe and compare how much students use the materials in two different courses on the 2nd semester Digital Electronics and Programming (id 62734) and on the 4th semester Digital Design (id 62711). To answer these questions, we use data from Learn. And we conduct two qualitative surveys, one about students' motivation, (Sekala, A et. al, 2023) and the other one as a part of the final course-evaluations in spring 2023.

1. INTRODUCTION

In daily teaching, some of us wonder about students asking questions which could be answered if they had been visiting Learn with the content for the given lecture. Some students do not use the materials on Learn very often, and more or less the same students have trouble with group-work and in completing the assignments to be handed in. This leads to this research to figure out the kind of materials used and correlations to exam. For two decades or more, we have used learning management platforms at DTU. For the last 6 years we have been using a system called Learn from the company Brightspace. The system has different features such as file-sharing, assignment, survey, quiz, peer grade, self-assessment. The content is organized in learning-modules used as a Lecture container with slides, quizzes and/or surveys, videos and links to external sources. Below in the paragraph 1.1 we describe the students' general background belonging to generation-Z (gen Z). And in paragraph 1.2 we describe teaching method and content in two courses used as case for this study.

1.1 Generation Z and learning

In this section, we present findings from literature about Gen Z and how they prefer to learn. Gen Z is defined in the literature as being born the earliest in 1995 and up to now. The generation overlaps with the millennials (Dolot A. 2018). Gen Z are practical, self-learning, engaging, active learners, prefer short lectures (Mosca J. B. et.al. 2019), (Cook V. S. 2019). The gen Z's are used to having 24/7 access to resources. They prefer to learn just in time. Teachers should guide the students how to use the different devices in a learning context (Cook V. S. 2019). The students have high expectations of their learning environment (Cook V. S. 2019). Research shows the students retention is short 8-10 seconds or else they shift focus to different input of information (Nicholas, A. J.2020). Students expect teachers to help them make sense of overwhelming amounts of information rather than transferring knowledge. Teaching is moving from the authoritative to the more facilitative way, for helping students connect their knowledge to applicable situations (Cook V. S. 2019). Gen Z likes the intrapersonal learning pre class homework and then have the social learning approach in the class with discussions and activities. A hybrid learning opportunity with online modules where they can asynchronously study when they like will also fit the Gen Z preferences (Seemiller C., & Grace, M. 2016). Therefore, the classical pedagogical approach with lectures and exercises afterwards could be changed to flip classroom teaching principle. This could confirm it's appropriate using this teaching principle in the two courses used as case in this article. In the next paragraph we describe the flipped classroom principle in the two courses.

1.2 Courses used in this research

Here we briefly describe the pedagogical method used in the two courses. The courses are: Programming and Digital Electronics (DEP) on the 2nd semester and Digital Design (DD) on the 4th semester. We will here short introduce the uses of teaching materials and the performed teaching method. In both courses we use flipped classroom, which means students need to prepare by reading text-book, watching a video and answering a quiz related to the topic for the coming lesson.

In DEP: The course book for DEP is bought as an e-book. For Program development the students use programming-IDE from Microchip studio installed on their own laptop. Students undertake programming assignments for configuring microcontroller registers and solve different data interface problems. Besides this, they are taught in general digital interfaces. The lecture typically starts out with a student discussion based upon questions about the lecture topic and then the quiz answers in Learn are opened up and discussed. Thereafter, we briefly explain the slides with code snippets among other things. The students work on assignments in groups of 2 to 3. They hand-in 4 compulsory assignment reports. And the exam is oral based upon questions and the last assignment.

<u>In DD:</u> The students buy the course book as a paper book. For hardware description the students use Xilinx IDE Vivado running on a server students access. In the DD, students describe a Central Processing Unit (CPU) in a hardware description language (VHDL) and implement it in a Field Programmable Array (FPGA) from Xilinx. Besides this, they are taught in general digital design of CPU'es. Each lecture is short with points from the book about the digital design of CPU and small snippets of the VHDL's constructions. Thereafter, the students work in groups of 4 to 5 on three compulsory assignments, each with a report, leading to a complete CPU-design, which in last course week (week 13) can process small programs. The exam is a written multiple choice test and a final report covering all assignment is evaluated.

METHODOLOGY

To understand the students general background we as mentioned in the introduction conducted literature studies to find descriptions of generation Z (Gen-Z) as learners and their preferences for learning. And as empirical data we use quantitative data from the courses described above in paragraph 1.2. The data reveals students' engagement with the slides, quizzes, video, and video-demos about different aspect of programming in the Learn system. For getting qualitative data about the preferred leaning materials we use two questions in a survey in another study (Sekala, A et. Al, 2023). Lastly the final course-evaluation qualitative data are used for eventually finding explanations about why students use materials on Learn as the data reveals. Data selection is further described in 2.1.

2.1 Data selection

From Learn we can extract different reports. A top-level report can tell us about how many students have accessed the different learning modules and how long they have been doing it in total. We collect data (for year 2021, 2022, 2023) about how many students use the preparation materials which consist of slides, video, quiz and the lecture slides and video-demos. Video-demos are practical hints for using different, programming constructs, simulations and settings in the IDE (programming editor) and explaining behavior of the code. In addition, quiz scores are extracted as well for answering the research questions about the eventual correlation between quiz-score and exams-grades. We also present data showing the completion of the course, which means if a student has accessed all materials, then the score is 100%. To know more about students' preferences for learning-materials we use data from one question: "Do you use any other sources apart from class notes to supplement your knowledge?" in another survey (Sekala, A et. al, 2023). And we have this semester added extra questions to the final course-evaluation about the uses of materials. In next section 3 Results, we present the findings founded on the data described above.

3. RESULTS

Here, quantitative data extracted from Learn and qualitative data from questions used in surveys are presented. In part 3.1 we present the quantitative data extracted about the uses of slides, videos, quizzes and video-demos. In part 3.2 we present the grades achieved and the score in quizzes to study if there is a correlation between grades and quiz score. Lastly, in part 3.3 and 3.4 we present from surveys the qualitative data about preferences for learning materials.

3.1 Data from Learn

From Learn, we extracted data about how many students accessed to the different kinds of materials. Figure 1 shows the box-plots for students' relative access to materials. The number of enrolled students in course DEP on the 2nd semester during the three years is 55, 52, and 49 respectively. And enrolled in DD on the 4th semester during the three years are 62, 67, and 57 respectively.

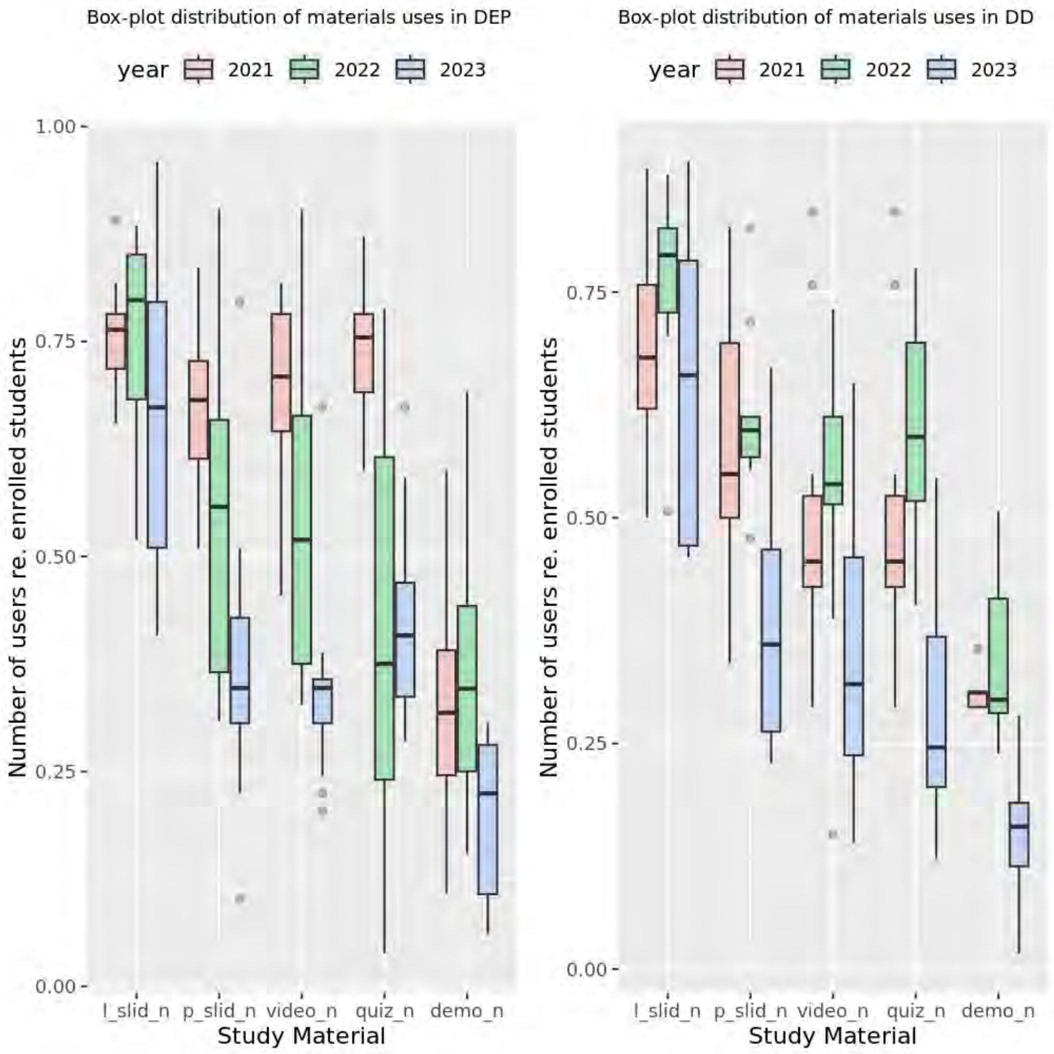

Fig. 1. Relative number of students using study materials in course DEP and DD.
On x-axis: l_slid_n slides and video demos (demo_n) used in the lectures. For preparation before lecture: slides (p_slid_n), quiz (quiz_n) and video presentations of

slides (video_n). On Y-axis: the number of actual users divided by the total number of students enrolled.

The Covid pandemic in 2021 closed the face-to-face lectures. Therefore, the students participated in the online lectures using Zoom and received supervision through Discord. The students in DEP 2021 show persistence in the lectures and in the preparation. The access to preparation-materials: videos and quizzes is much higher in 2021 than in 2022 perhaps because everything was online. Whereas DD students show 15 -20% less engagement with the preparation. The students in DEP in 2021 are the same students in DD 2022 and they still are more persistent in preparation compared to students in 2023 and 2021. If we look at the DEP year 2022 and year 2023, they are most active using the slides for the lectures and are not so engaged in being prepared by using the materials. Similarly for the students in DD 2021 and 2023. Perhaps students show lack of interest using online materials as a post Covid reaction. As well as participating in lectures and using slides is also less compared to 2021. In general, the students in the semester 2023 are less active compared to the two previous semesters regarding preparing by using materials provided on the Learn. Lastly, from figure 1 we find fewest access the video-demos (demo_n).

3.2 Degree of completing topics/quizzes on Learn and grades.

Table 1 on next page shows the individual grade and students' overall completion in percentage task/topic by visit in Learn. Available topics for DD from 2021 to 2023: 129,135 and116 respectively. And for DEP from 2021 to 2023: 142, 169 and 148 respectively. In 2022, for the DEP course the EM(not attending exam) is up to 8 students and one got the grade 0 (not passed) and two students got 02.
In 2021, in the DD course, two students did not enroll for the exam, one completed by 61% course-materials and the other one by only 3% therefore this huge standard deviation of 10.
Moreover, in DEP in 2021, 5 students did not enroll for the exam and with a range of completions from 68% to 0% completions. The reason for getting no exam is that students often fail in group work for social or learning reasons, and therefore do not hand in assignments, which is required for attending the examination for both courses. Especially for the DEP course, up to 30% of the students do not obtain the exam the first time. As one student said by the final evaluation in 2023, “I have this semester prepared before the lectures and it goes quite well”. From Table 1 it is seen students with grade 10 (like A) and 12 (like A+) have a mean value of completion of 17% to 25%. The students with grade 4 (like a C) show mean values of completion variates 11% to 16 %. Whilst grade 7 (like B) shows above 22% of completion except in DD 2021, so higher activity than students getting a 4. The lower limit for passing is 02 and there is an interesting observation that they have actually been actively completing tasks from 11% to 22%. In both courses, which is comparable with a grade 12 where the mean value is 17% to 25%. An explanation for that is the way the grade is given - grading is based on evaluation of written report, a program, and an oral exam by 5 minutes presentation of a known question before exam, random chosen. Moreover, in the course DD the grading is based on an evaluation of a digital multiple choice and a report-documentation for the design of a CPU.

Table 1: Mean value and standard deviation (sd) for the completions in % grouped by the grade achieved by exam.

course	DEP 2021		DEP 2022		DD 2021		DD 2022	
Grade	mean	sd	mean	sd	mean	sd	mean	sd
NO*	10.00	10.12	3.00	1.00	13.67	5.13	19.50	20.51
EM**	10.67	9.42	10.80	6.37	8.50	10.60	16.25	16.52
0	12.00	5.66	24.25	9.03	No data	No data	29.00	NA
2	21.00	6.75	11.50	7.78	No data	No data	22.50	9.19
4	14.60	8.96	13.00	6.00	12.50	9.81	16.58	8.45
7	22.42	7.30	24.00	9.56	17.45	10.60	22.43	10.81
10	19.62	7.31	18.33	8.87	24.19	9.34	22.45	10.64
12	16.83	4.07	23.75	4.69	25.33	2.08	19.50	6.81

*did not register for the exam, **did not attend the exam.

Students who have not been writing any code very seldom get a grade above 4. In course DD, when we compare with figure 1, the activity in spring 22 is high and therefore the percentage completed becomes higher (Table 1).
An assumption has been that the quiz score for the students and the final grade is related - a high grade means a high score in the quiz. To test the hypothesis, we used a dependent t-test, and we did it for the spring semester 2022 quiz data in both courses: It reveals that there are no dependencies between the score in the quiz and the grade. For DEP t-test shows: t = -11.489, df = 38.317, p-value = 5.593E-14 as t is negative and p-value very small, it implies no dependencies.
For DD t-test shows: t = -19.088, df = 61, p-value= 2.2E-16 as t is negative and p-value very small, it implies no dependencies.
The hypothesis is that the more active students are in the Learn, the higher the grade. A t-test was using the same data as in table 1 and the grades,
For DEP t-test shows: t = 12.869, df = 59, p-value= 2.2E-16, as t is 12 and p is close to zero the hypothesis is false. For DD t-test shows: t = 13.068, df = 38, p-value = 1.236E-15, as t is 13 and p close to zero, it implies no dependencies.
It should be noted here that the number of students enrolled in the courses are between 49 and 67 and the grades is not normal distributed.

3.3 Qualitative data from final course evaluation

In the final course evaluation in 2023 for the two courses (DEP, DD) we asked three questions about the use of the materials:

1. Which material(s) on Learn in DEP/DD most supports your learning and why?
2. What materials on Learn in DEP/DD give you the least learning and why?

3. Which material(s) on Learn in DEP/DD do you use least and why?

In the DEP course, twenty-four students answered the general evaluation and twenty-one answered the first question, sixteen students answered the 2nd question and fourteen students answered the 3rd question. In the first question, ten commented: “the videos are good for preparation” and seven students wrote: quizzes are good. The Datasheet about the microcontroller was mentioned as a source for learning. The least learning comes from the e-book. In general, the answers were very diverse.

In the course DD, twenty-six students answered the general evaluation but only fifteen answered the first question, seven students answered the second question and eight students answered the last question. From the answers to question 1, five students expressed that the videos are helpful. Five students expressed that the project assignments about CPU design give the most learning. One complained about too much material on Learn. The answers to the second question, the lectures, and the quiz give less learning. As answer to the third question, one wrote: “Preparation before lessons - Do not have time”. And three students wrote that the different kinds of guides/demos are used less.

3.4 Qualitative data about use of alternative materials

Figure 2 shows the result for one of the questions used by Sekala, A et. al, 2023: “Do you use any other sources apart from class notes to supplement your knowledge?” . 26 students answered in DD (62711) and 22 students answered in DEP (62734). 60% of the students in DD (62711) and 50% in DEP (62734) try to find alternative materials on their own. Only 46% in DD use the recommended book and 36% in DEP use the e-book. And 71% use the internet in DD and 50% in DEP use the internet.

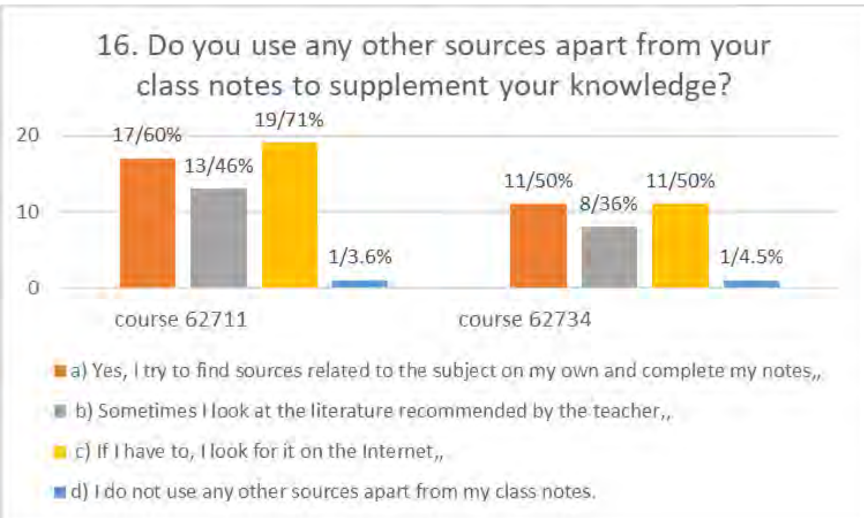

Fig 2. Students use other source in DD (62711) and DEP (62734)

This results can perhaps explain why students don't interact with the materials on Learn. In addition, regarding Gen Z students, who are used to being connected to the internet 24/7, prefer searching on the internet instead of logging on to the Learn and thereafter trying to find the relevant materials in folders. A few students at the midterm evaluation and the final evaluation have remarks such as “too many materials it’s very hard to find things”. Perhaps the way the materials are organized also explains the lack of uses. But in addition, in the attitude of self-determined learning it can explain how they find their own materials, which gives meaning. The article by (Bond, M. et al. 2020) has done a literature study about students' engagement in relation to learning technology. And they describe the engagement in 3 categories, behavioral, cognitive, or affective indicators. Having that in mind, the results shown here could for the remaining group of students who use the Learn very little or not at all be explained by the disengagement factor as frustration. This fits with the students' oral feedback when we discuss course evaluation of the DEP - “It is very hard to understand how programming of registers is done and that it differs much from c-programming in general”.

4. DISCUSSION AND CONCLUSION

The answers to the research questions are up to 70 % students accessed most of the lecture slides and secondly, most of the preparation slides. Thereafter, they the do the quiz rather than watching the video. Only a few accessed the video-demos. An explanation for not watch the demo videos is as a student said in the final course evaluation “it’s hard to know where the demo is we miss a complete list over demos”. There is no correlation between the overall students’ access to the materials (completions) and the grade at the exam, neither the quiz score nor the grade at the exam. The reason for that is that the work with the assignments does not necessarily depend on the materials in Learn as the students can find answers on the internet and by asking the supervisor for help. Moreover in DEP, the grading at the exam depends on a report and an oral exam and in DD digital exam and the evaluation of the report does not directly depends on the activity in Learn. It is striking that our data shows Gen Z students are not engaged in preparing themselves by using materials on Learn, when they are described in the literature as self-determined and self-directed (Cook V. S. 2019) would rather watch a video than read (Nicholas, A. J.2020). One student, in the final course evaluation for DD, wrote “I find it easier to watch a video and take notes than to read 20 pages of the book, although it is clearly best to do both”. Regarding the flipped classroom, only approx. 50% of the students do not do the quiz before the lecture. An explanation for not all students do the quiz, is that the teacher does not enforce that students to do the quiz before lecture. In the next semester we will try to enforce that. Another explanation for students don’t use Learn-materials, can be by the programming assignments does not link directly to materials on Learn. And when programming they don’t necessarily need to use the materials on Learn. But it is strange that only 10%-30% of the students use the video-demos, as students who have used them responded positively as shown in part 3.3. A reason could be the way the video-demos are embedded in the lecture-folder. In the future the video-demos will be in its own folder. Another explanation for not using materials: The workload is high and this stresses the students so they prioritize their time on the assignments instead of using materials on Learn. In general, students learning programming do not dependent on materials offered in Learn. Maybe the structure and access facility does not faster quick answers compared to “Googling”. To conclude, data from LMS give knowledge about students’ activity. There is a challenge in using flipped class room when students does not meet prepared which unfortunately the data reveals. That rise the questions about organization of materials and the students workload as well as enforcing the students need of being prepared before lecture.

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THE IMMERSIVE PLACEMENT EXPERIENCE: SINK OR SWIM?

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Keywords: *Diversity, Industrial Placement, Communication, Training*

ABSTRACT

To excel in their respective engineering fields, engineering students need to be equipped with a combination of technical and interpersonal skills. Central to excellent interpersonal skills is good communication. The aim of the study is to evaluate how well-prepared mechanical and design engineering students felt entering into their industrial placements, using a UK university as a pilot case study. For the study interviews were carried out with final year students who had previously completed an industrial placement year, focussing on communication, workplace diversity, technical working methods and university teaching styles. Reponses were anonymised, coded and analysed using quantitative and qualitative methods. Nine

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engineering students were interviewed regarding their placement experience and were asked to rate how well they thought their engineering programmes helped in developing these skills. Two key findings were: 1) students on average spent 60 % or more of their placement work using their communication skills and 2) students felt more could be done to prepare them for individual presentations and individual projects before placement. On average the students felt marginally more prepared with the interpersonal skills element compared to the technical skills element. The survey also highlighted that the students' understanding of what falls under the umbrella of workplace diversity was narrow, and they did not classify skill differences as a component of diversity. The student's honest feedback allowed a collation of proposed recommendations for both the mechanical and design engineering courses.

1 INTRODUCTION

1.1 Background

A person's personality and ability to contribute in a work environment, branded by experts as 'human engineering', accounts for 85 % of commercial success in industry[1]. The engineering workplace also seek interpersonal skills such as time management, customer orientation and, in particular, good communication[2]. In almost every industry it is evident from the job specifications there is a heavy weighting on these specific competencies. Within the UK engineering industry, 60 % of engineers said they valued good communication skills[3]. The challenge at university is preparing students to enter a workplace that is intergenerational and cross-disciplinary, which suddenly opens students to the diversity of different workplace cultures, technical language barriers and different working processes, something that is not easily simulated in the classroom, despite team-based learning and other active learning approaches widely adopted.

Diversity is more commonly known as the extent of human differences[4]. Equality, diversity, and inclusion are all aspects that employers embrace through their employment policies under the UK Equality Act 2010. By UK law, there are nine protected characteristics: age, gender reassignment, marital status, pregnancy, disabilities, race, belief, gender, and sexual orientation. However, diversity is a subject that is much broader and includes many other aspects such as culture, working styles, experiences and so on. This phenomenon has been coined in various articles on diversity and inclusion as the "Iceberg of Diversity". Organisations are now monitoring how diverse their workforce are and are striving to make their departments more diverse[5]. A diverse employee directory results in staff with varying 'cultures' mixing together and so, methods of communication within a department, or even a team can be very broad – something which engineering students will need to have a firm grasp on to ensure they are able to work effectively and efficiently.

Teams which are diverse are also 87 % better at making decisions[6].As engineering is a field in which collaboration is a common workplace practice, it is vital that engineering students are well equipped with the tools to communicate across disciplines prior to entering the workforce. Good interpersonal skills increase workplace productivity and group contribution[7]. However, studies show that engineering students are spending a mere 5 % of their time preparing for this[8]. Conflict is also inevitable in team-working environments, which tend to increase within diverse teams and requires appropriate conflict management skills, another key interpersonal skill. However there is such thing as an optimal level of conflict, which has proven to boost individual performance, increase team efficiency and encourage healthy competition within teams. A positive byproduct for companies in cases where diverse teams are managed well.

The research question for this study: are students who have completed year 1 and 2 in an engineering programme and entering their placement well equipped with the skills to work in an engineering working environment?

The aim of the study is to evaluate to which extent the university prepares mechanical and design engineering students for industrial placement using the authors' host institution as a case study. Interviews will be used to focus on communication, diversity, workplace conflict and the university's teaching methods to evaluate student perception on their development of technical and interpersonal skills at university.

2 METHODOLOGY

2.1 Data collection

Prior to starting the study, an ethics application was submitted and approved by the Engineering and Physical Sciences Research Ethics Committee at Aston University. A risk assessment was also submitted to ensure the safety of the interviewer and participants. This included how to mitigate potential cases where the interviewee may divulge company secrets or describing conflict which may have been traumatic et cetera. Interviews were conducted with students who have completed an industrial placement. The inclusion criteria of the participating students final year mechanical and design engineering undergraduates between the ages of 21 and 24 at Aston University who had completed a minimum of 25 weeks' placement experience. Interviewees were contacted via word of mouth, internal Microsoft Teams chats, email invitations, and through social media messaging. Once the students had agreed to participate, they were provided with the participant information sheet, signed a consent form before proceeding with the interview. The interviews were carried out online via Microsoft Teams and their responses were recorded and transcribed through the software. The participants were made aware through the consent form that the audio and transcription would be recorded to allow the researcher to refer to any comments made for the post-analysis and that they will remain unidentifiable. The participants were asked the same series of questions in four categories: communication, diversity within the students' team, workplace conflict, and whether students thought their engineering programme succeeded in developing their technical and interpersonal skills in preparation for their industrial placement.

2.2 Post-interview analysis

Post-interview analysis was a mixed methods approach extracting quantitative and qualitative data from the interviews to evaluate findings. Quantitative data was conducted by coding the information collated using an open code method to extract key topics covered. This was manually conducted by the researcher. Two questions were also quantitative where students were asked to rate on a scale of 0-5 how their university programme had prepared them with the interpersonal and technical skills for their placement The codified quantitative responses were presented graphically. Qualitative data explored the experiences of the participants, where anonymised quotations were used to illustrate trends found.

3 RESULTS

3.1 Diversity within the team

A total of nine students were interviewed who were subjected to twenty-one questions regarding their industrial placement. When asked what diversity they could identify in their workplace and what would constitute diversity, students identified heavily with race, gender and religion as identifiers. It was also clear that students were not fully aware of other diversity identifiers within the nine protected characteristics and beyond (fig 1). However, 5 repondees did cite a characteristic beyond the 9 protected by law. These five includes: culture, different walks of life (2 students), education background and countries.

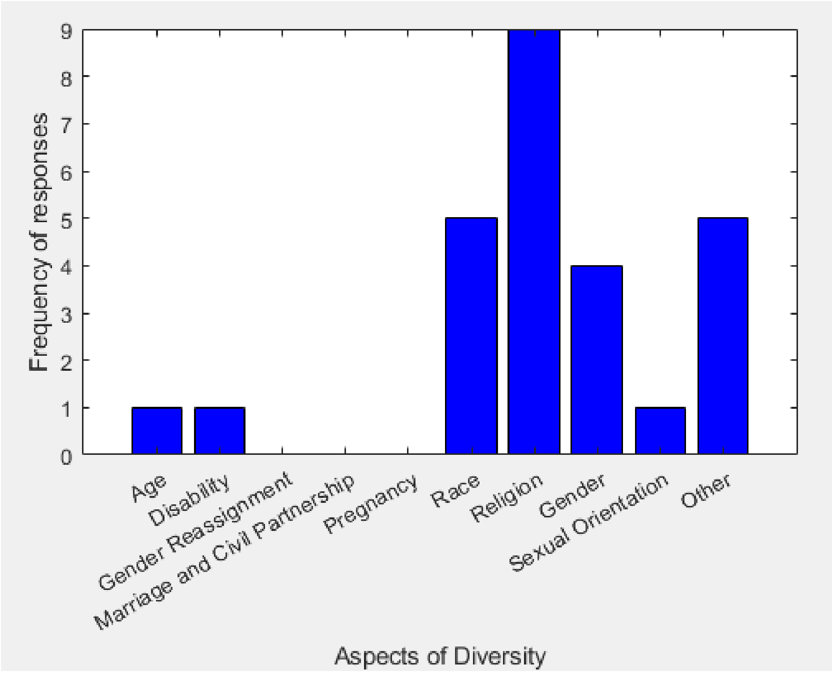

Fig. 1. Frequency of responses relating to the nine protected characteristics students associated with diversity showing a limited awareness of all characteristics and heavy emphasis on religion, race and gender.

3.2 Communication

A considerable proportion of the students' time was spent in communication during their placement. Of the nine participants interviewed, all but one student produced and collaborated on technical engineering work during their industrial placement. The survey results revealed that on average, the amount of time students spent communicating was 62.78 % +/- 24.12 SD with numbers exceeding 60 % for 5 of the 9 participants (see fig. 2).

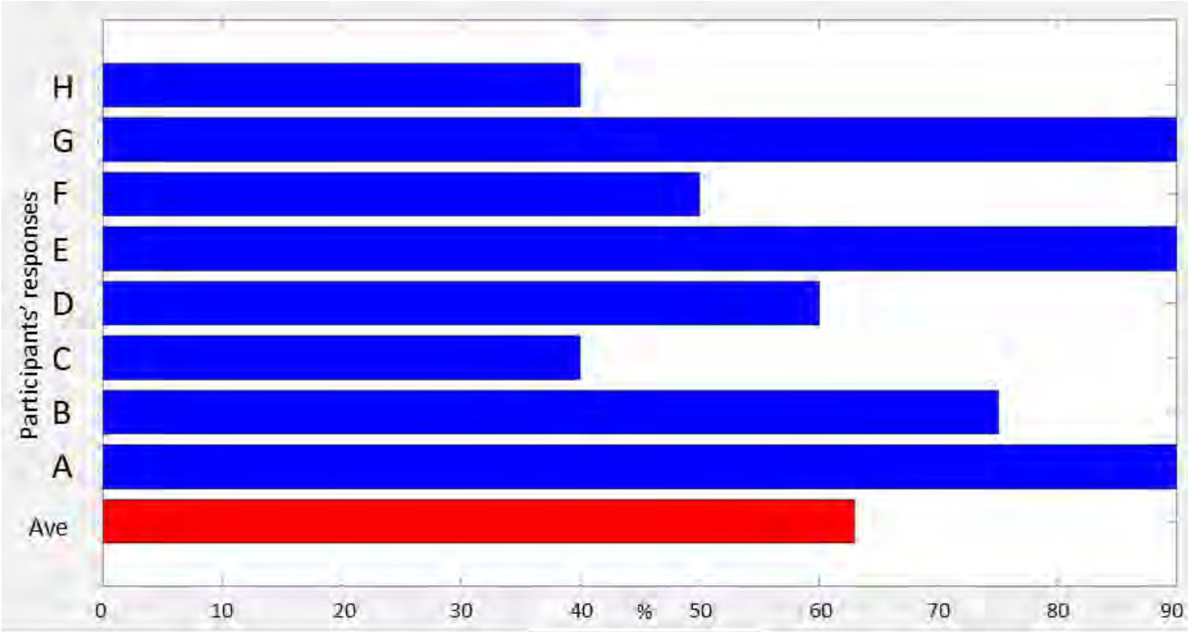

Fig. 2. Five out of nine students spent more than 60 % of their time communicating in their roles, with an average +/- standard deviation of 62.78 % +/- 24.12 across the group (red)

The students also highlighted that a wide range of communication types were used during their placement. This included face to face communication, emails, presentations, phone calls, meetings, Microsoft (MS) Teams, and WhatsApp Messenger. Most students (67 %) quoted that their workplace utilised MS Teams chats as the most common form of communicating followed by emails, face to face and meetings each constituting 11 %.

3.3 Preparation for interpersonal and technical skills in the workplace

Five students thought that the university could have prepared them better for individual communication skills with all students recommending how the university could have enhanced them. Students also quoted that they were very well prepared for technical aspects relating to CAD and manufacturing, although one student still thought CAD could have been improved.

Students were also asked to rate the university's efforts on instilling technical and interpersonal skills on a scale of 0 to 5 where 0 equated to the university providing no effort and 5 corresponding to the university helping immensely. For the interpersonal section, students gave an average score of 2.56 +/- 1.88 SD and an average of 2.28 +/- 1.72 SD for technical skilling. Interestingly, on average students thought that the academics succeeded in teaching and developing interpersonal skills better than they did at technical skills. This is noted from the higher average on interpersonal skills preparation, although it is also important to note the increase is marginal with a widespread and therefore may not be significantly different.

It is worth noting that the examined cohort of students were those who had primarily spent their university studies online due to the Coronavirus pandemic completing their year 1 and 2 during 2019-20 and 2020-21 respectively. Therefore, four students, such as participant B, thought university offered little to “no support” as students “spent most of the time working online” and claimed that they had the “soft skills already from previous experience.” Participants C and G also stated that their interpersonal skills were gained from previous employment rather than university development. The switch from in person to online based learning affected students’ people skills. This observation is supported by Participant F’s experience who commented that they thought their interpersonal skills did not excel as a result of online classes. The responses from the technical skills development aspect revealed that students thought the university partially succeeded in their transmission of technical skills as they mentioned 3D CAD as being particularly useful.

4 DISCUSSION

4.1 Diversity in the workplace

Students identified a narrow scope in their workplace diversity, which was largely focused on race, gender and faith. All interviewees were generally unaware or did not mention of most of the nine protected characteristics. However, five students did mention a characteristic beyond the nine protected by law, which indicates an awareness of the wider scope that diversity includes (the diversity iceberg). The students that identified as being from a minority group listed more diversity characteristics compared to other students, although this finding is speculative due to the small numbers. This finding may indicate a heightened awareness of their own positionality in society and that of others they work with. It was evident that students’ knowledge on diversity is limited and highlights a potential gap to address at university. It can be said that by studying in Birmingham, a city with an ethnic minority majority[9], students have spent their last 4 years interacting, socialising, studying and carrying out group work with people of different races which gives a rationale as to why these aspects were mentioned the most. Diversity is known to spark innovative solutions which is a desired component of any team, particularly a team of engineers. Knowing that companies would benefit economically with more diverse teams, it would be interesting to explore how companies define and capture diversity.

4.2 Communication

On average, students found over 60 % of their role was linked to communication with Microsoft Teams chats being evidently very popular amongst industry professionals as two thirds of students said it was the most subscribed form of communication at their placement. Students mentioned that their company opted for an agile remote working policy to reduce the exposure and spread of COVID-19. However, participants also mentioned that this practice remained in use well after the pandemic restrictions were lifted. Students A, F, H and J all reported that their workplace was very friendly and that everyone was "approachable" in the office as they would not hesitate to approach colleagues if they needed any help. However, they continued using Microsoft Teams as a form of communication despite the close proximity and friendly nature between colleagues. It is therefore evident that today's engineers were accustomed to the Microsoft Teams software as they found this to be an efficient, practical, and comfortable method of communicating, and so remained as their primary method of communication.

It was the student which utilised face to face meetings the most who did not witness friction or elements of conflict during their placement year. Every other student (with the exception of Participant E) mentioned that they experienced some workplace conflict. Although the sample size is small, one can speculate that specific modes of communication are preferred for reasons unrelated to productivity or ease of use but rather a way to avoid social interactions that could lead to conflict. In a literature review, Kahlow et al. (2020)[10] comments on the use of email as a conflict avoidance strategy and online working reduces the opportunity for colleagues to address and discuss problems, something that can lead to changes in values and preferences. On the one hand, technology may assist organisations in reducing levels of workplace conflict by removing face to face onsite work. On the other hand, the reduced frequency of face-to-face interactions employees have can pose a problem as it may be detrimental to employees accepting diversity. This reflection is speculative and would require further study.

4.3 Preparation for technical and interpersonal skills

The average scoring obtained from the questions pertaining to the university's methods of technical and interpersonal skills development, were comparable with students responding more positively towards interpersonal skills. This is surprising given that the university course is split 50-50 in terms of the theoretical knowledge and application through experiments, group work, laboratories and individual assignments. The responses from the interpersonal skills aspect highlighted communication is a key area in which students required more assistance. Over a third of students (4/9) thought that "more presenting" was needed in the course, specifically "individual presentations, not group presentations". Presenting was a huge proportion of their job role with all participants mentioning that they presented to someone (superiors), which included managers, directors, and board regulatory members, so a high level of professionalism was required of them. This explains why all the 4/9 students expressed that they wished their degree had more "individual projects" and presentations.

5 SUMMARY AND ACKNOWLEDGMENTS

Engineering industries look for employees that not only possess the technical knowledge required for the role, but equally the interpersonal skills needed. The study highlighted the key points that a wider understanding of diversity is needed, widing the communication training is also needed so it is not limited to team working but includes individual ownership through presentation practice, and how to deal with workplace conflict. Although these factors are addressed in the final year when students return from placements, this study reveals some of these skills should be introduced earlier in the programmes.These recommendations are driven through the student experience and will better prepare students for industrial placements. This study was approved by the university's Engineering and Physical Sciences Research Ethics Committee.

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Supporting women in Science, Engineering and Technology programmes: A TU Dublin approach

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Equality Diversity and Inclusion in Engineering Education

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Abstract:

The under-representation of women studying engineering in higher education is gaining increasing attention in Universities throughout Europe and other jurisdictions. This has led to under-representation of women in many of the professions in the Science, Engineering and Technology fields also. Numerous initiatives and programmes are being developed in universities to gain more information about the embedded issues in these disciplines that inhibit female applicants or lead to unsuccessful outcomes in university programmes. One such initiative that has been developed and piloted in Technological University Dublin (Ireland) is a mentoring programme called 'Equality in Science and Technology by Engaged Educational Mentoring (ESTeEM)'.

This paper reflects on the development of the ESTeEM programme, which is a unique, award-winning mentorship programme for female students, including non-binary and transwomen in Science, Engineering, and Computing programmes. The ESTeEM programme has been piloted to students pursuing programmes at many levels in the university, including craft-based apprenticeship programmes, through to Higher Certificate, Honours Degree and Postgraduate programmes in Engineering, Science, and Computing. This paper outlines the origins of the ESTeEM programme, the experience of the facilitator and participants from the pilot programmes, as well as the initial contributions to the wider University community, through strategic priorities being achieved, in addition to increased participation and success of women, non-binary and transwomen successfully pursuing Science, Engineering and Technology Programmes. Finally, the paper concludes with lessons learned and suggestions for further roll-out and development of the ESTeEM programme.

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1 Introduction:

The lack of equality in terms of gender and racial diversity in the professions aligned to Science, Technology, Engineering and Mathematics (STEM) has been recognised for many decades (Kanny et al. 2014). There is increasing international scrutiny on the causes and the development of potential solutions to combat the obvious inequalities in the STEM fields, but the search for a panacea continues. Some progress has been made in terms of raising awareness through discussion platforms, and policies at international, regional, corporation and university level, but success remains somewhat elusive (Dunne et al., 2022, Gagnon et al., 2021).

The causes of gender and racial inequality (not to mention other forms of inequalities, bias and rejection) are multifaceted and intergenerational with history, culture, education, socio-political factors, and societal attitudes all playing a part (McGinnity et al., 2018; Pineda and Mishra, 2022). Consequently, the definition of EDI remains broad and has multiple interpretations and applications. This is due to how these variables differ across the world, therefore influencing what EDI means in different regions (Pineda and Mishra, 2022).

For the purpose of this case study, the definition of EDI is '*...the fair treatment and opportunity for all. It aims to eradicate prejudice and discrimination on the basis of an individual or group of individual's protected characteristics'* (The University of Edinburgh, 2021). The context of this particular case study revolves around the issue of gender equality in STEM. Other broader issues relating to diversity and inclusion, whilst equally important, are not the main focus of this case study.

1.1 Women in STEM: The Landscape Ireland

Women in Ireland have seen many advances in gender equality over the past 50 years, beginning with the removal of the Marriage Bar in 1973. While there were relatively few women pursuing professional careers before then, this laid the foundation for increasing participation of women in higher education programmes and professional careers. Ireland's membership of the EU (formerly the European Economic Community (EEC)) brought forward changes in regulation, legislation and for wider society in Ireland. Despite these positive developments, gender inequality persists across many domains in Ireland including income parity, housing, leadership, and employment rates (Barrett et al., 2022; King, 2022). For example, the overall employment rates for women in the Republic of Ireland remain below those elsewhere in northern Europe, including the UK and Northern Ireland, and the gender pay gap for Irish women continues to persist (K., 2022; PricewaterhouseCoopers, 2023).

Within the sectors of Engineering, including the craft apprenticeship, Computer Science, and Information and Communication Technology (ICT), both in higher education and in employment, the lack of women, including non-binary and transwomen, persists. Only 18% of Irish ICT graduates and 20% of computer science graduates are female (TechCentral, 2021). Given these figures, it can come as no surprise that as of 2022, only 32% of ICT workers in Ireland are women (O'Dea, 2022). In engineering, Engineers Ireland (2022) reported that only 23% of the engineering graduates are women, but the number of women within the engineering workforce is substantially less at 12%. This phenomenon known as the 'leaky pipeline' (Darmody, 2022; Engineers Ireland, 2022; Grimson and Grimson, 2019). In craft apprenticeship, women make up a scant 1% of participants (Department of Further and Higher Education, Research, Innovation and Science, 2022). In addition, it is accepted the LGBT+ (Lesbian, Gay, Bisexual, Transgender +) community is under-represented in third level and the STEM disciplines workplace (STEM Women, 2021). This data clearly reflects the gender disparity that is present in higher education as well as the STEM workplace.

1.2 EDI and Mentoring:

Mentoring is gaining popularity across several areas including higher education as well as in enterprise as a tool to effect real change. Recent research has demonstrated how, now more than ever, it is important to include equality, diversity, and inclusion (EDI) issues as part of the mentoring process. There are mentors and mentees who will have already experienced systematic barriers in their lives, and some participants will still be experiencing these impediments. Therefore, recognition and understanding of what EDI is, and the impact these barriers can have on underrepresented groups are vital to the mentoring process (Dahlberg and Byars-Winston, 2019; Deanna et al., 2022). Within the higher education context, as well as other contexts, if a mentor lacks cultural awareness about their mentee, they may fail to recognise their mentee's important accomplishments and milestones. This, in turn, has the potential to negatively impact the outcomes for the mentee (Cornwall, 2020; Dahlberg and Byars-Winston, 2019). An individual's self-identity is important to understand how people view themselves, and this includes gender identity, ethnicity, place of birth, values, hobbies, etc. Some aspects of identity are fixed over a person's life and other parts are more dependent on the social context and the stage of life a person is at (Dahlberg and Byars-Winston, 2019). People can hold multiple identities at any given time (for example, I can be a mother, a sister, a daughter, a wife/partner, a student, a care-giver, etc.). Therefore it is important to be aware of how individuals will not have the same experiences even if they share similar identities. For example, a mature student will have a different experience in college when compared to a student who is on the autism spectrum, and their experiences will be different to the third level experience of an international student, even if they are all on the same programme (Bauer et al., 2021; Dahlberg and Byars-Winston, 2019).

1.3 Mentoring and the Benefits for the Students, Staff, and the University

Considering the diverse groups of staff, researchers and students present in TU Dublin, it is important to include equality, diversity, and inclusion (EDI) as part of the induction and training process both for staff and for students. Some of the mentors and mentees will have already experienced systematic barriers in their lives and others will still be experiencing them. Therefore, awareness and knowledge in this area is vital to assist in creating equal opportunities for all parties in TU Dublin. When EDI is incorporated into mentoring initiatives it leads to many positive outcomes for both mentors and mentees in the domains of academic progression, career satisfaction and advancement, plus there are also psychological benefits more generally (Clutterbuck, et al., 2012; Dahlberg and Byars-Winston, 2019; Deanna et al., 2022).

In the higher education sector, students, university staff as well as early career researchers report numerous gains from participating in mentoring programmes. This in turn benefits the university. Mentoring is an aid for student retention (Bhatia et al., 2013; Rosillo, et al., 2018). Students who engage in mentoring initiatives describe feeling a stronger sense of community and a feeling of belonging, both within their academic programmes and within the university (Beauchamp et al., 2021; Kram, 1983). Mentoring also assists students with the acquisition of subject knowledge as well as with the development of academic skills. This, in turn, leads to an increase in motivation and commitment to studies (Dahlberg and Byars-Winston, 2019; Rosillo, et al., 2018). These benefits are more pronounced for students who are from underrepresented groups, including women who are in STEM programmes (Dahlberg and Byars-Winston, 2019).

Mentoring also benefits new students. It assists with the transition to the educational demands of higher education and the other challenges associated with this developmental stage (Bhatia et al., 2013; Cross, et al. 2019; Kram, 1983). For the students who encounter difficulties adapting to this transition, their academic outcomes tend to be less favourable. This leaves this population at a higher risk of withdrawing from their programmes of study (Foy and Keane, 2018; Lowe and Cook, 2003).

For the university staff, including early career researchers, who engage in mentoring programmes, they report a variety of gains including broadening their professional network, professional support, obtaining career-related insights and developing work-based competencies and knowledge (Carmel and Paul, 2015; Deanna et al., 2022). Another mentoring outcome is feeling an increased sense of satisfaction with their employer which positively impacts the retention of these staff. (Cross, et al. 2019: Fishman, 2021; Nick et al., 2012).

Because of the breadth of applications for mentoring in a University context, for this case study, mentoring is defined as: *the purposeful and intentional commitment on the part of the mentor to the growth, development, and success of the mentee to facilitate that person's career and personal and/or academic development* (Baker and Griffin, 2010; Roberts, 2000).

2 Equality in Science and Technology by Engaged Educational Mentoring (ESTeEM):

ESTeEM was piloted in 2017 by the School of Electrical and Electronic Engineering, City Campus, TU Dublin in response to two factors: the low recruitment of women, including non-binary and transwomen, into Engineering programmes and craft apprenticeship in TU Dublin, and the retention of these students. In 2018, the remit of the ESTeEM programme was expanded to include the disciplines of Computer Science and ICT. The ESTeEM programme became an award-winning mentoring programme for female students, including non-binary and transwomen, as a successful collaboration between industry and TU Dublin. The current industry partners include ABB, Amazon, Arup, DBFL, Dublin City Council, Eaton Intelligent Power, ESB, MasterCard, SAP, and Schneider Electric. In April 2018, Athena Swan selected ESTeEM as the example of best practise.

The development of the ESTeEM programme was shaped by gender equality research in education and STEM subjects as well as from research pertaining to women and mentoring. In 2015, research from the Organisation for Economic Co-operation and Development (OECD) and from Accenture identified how adolescent girls lacked confidence in their abilities with STEM subjects. These reports noted the lack of women STEM role models may be a contributing factor to this as well as the concerning persistence and strength of the prevailing stereotypes held about the types of careers women ‘should’ be pursuing (Accenture, 2015; OECD, 2015). Further longitudinal research examined the factors that impacted the retention rates of women in higher education engineering programmes and in the engineering workforce. The data demonstrated it was the culture both in higher education and in the workplace that influenced women to leave engineering (Seron et al., 2015). The women from the study spoke about being treated in a stereotypical gender-specific manner while in higher education and in the workplace, including programme related internships.

Many of the women described experiencing gendered stereotyping from fellow classmates, lecturing staff and co-workers. Some women also reported being subjected to sexual harassment and being isolated when in internships and/or the workplace. The women in the study reported these were the reasons they chose to leave engineering (Seron et al., 2015).

When women are mentored by other women in a professional setting, Neal, Boatman and Miller (2013) found that the mentees experience beneficial career related outcomes both in the short term and in the long term. It was found this was even more worthwhile when the women were working in predominantly male environments. Interestingly, Chesler (2002) demonstrated how women-to-women mentorships created a more collaborative and supportive community amongst the other female employees instead of one based on women competing against the other women in the company for promotions and other opportunities. The latter more commonly arises when women were mentored by men and when there are few women in senior roles.

2.1 Purpose of ESTeEM:

Based on the findings of these studies, it was decided ESTeEM would address these factors in TU Dublin. Female students from relevant engineering, computing and ICT programmes, as well as from apprenticeship programmes, would be mentored by women from a related discipline in industry. The purpose of this is to assist the TU Dublin students in recognising they have the aptitudes needed to undertake not only their chosen programme of study but also a career in their chosen profession. As part of the mentoring, the student participants would develop a broader understanding about their chosen profession, the range of career paths available as well as details about the skills required to be a successful STEM graduate.

2.3 Format:

Annually ESTeEM holds five lunch events as well as an induction for the students and an induction for the mentors. The TU Dublin staff who assist at the lunch events are invited to the mentor's induction. Planning for ESTeEM events begins on day one of the academic year. The dates, themes and speakers for each event are discussed and agreed and the recruitment for industry mentors, student mentees and TU Dublin staff begins. All participants are volunteers.

Once the mentor-mentee matching has occurred, students attend an induction session. The purpose of this is to outline the ESTeEM programme, what is required of the students and details about the mentors. The mentors are also provided with an induction which includes mentor skills training and details about the mentees. The TU Dublin staff who volunteer at the ESTeEM events also attend the mentor's induction.

Each ESTeEM event follows the same format. The welcome desk opens thirty minutes prior to the function commencing. Lunch is available at this time. Each event starts with a fifteen-minute talk by an enterprise speaker from one of the participating companies. The theme of each event focuses on the early career needs of the mentees. The remainder of the session is when the mentoring with the industry mentors and mentees occurs. After the final ESTeEM event, all participants are sent a survey to measure the impact the initiative has had.

2.4 Covid – from 2020 – 2022:

In March 2020, the fifth and final ESTeEM event of that annual cycle was postponed due to Covid-19. Due to the ongoing pandemic restrictions, it was decided to pilot an online version of ESTeEM. The online event, which was hosted in TU Dublin's virtual learning environment, Brightspace, was held in early June 2020. The feedback from the TU Dublin students who participated was that the online experience was poor. The preference for in-person, mentoring events was clear.

In September 2020, a cross-campus and multidiscipline group was established by Dr. Leslie Shoemaker. The purpose was to create four online panel discussions for the academic year. The companies that were already engaged with ESTeEM agreed to participate in these events. It was determined the theme of each event would focus on women, including non-binary and transwomen, who were in craft practice apprenticeships or who were in Engineering, Computer Science or ICT related programs.nInvitations to each online event for the 2020-21 cycle were sent to all female students, including non-binary and transwomen, across all TU Dublin campuses who were studying Engineering, Craft Apprenticeship, Computer Science and ICT. Invitations were also extended to second-level schools and Further Education Colleges in County Dublin.

Due to the ongoing restrictions in Ireland during Covid-19, a further four online events were held in 2021-22. The same format was replicated for these events.

3 Impact and findings:

Annually, the mentors, mentees and TU Dublin staff are surveyed to evaluate impact of the ESTeEM programme. Research by Crisp and Cruz (2009b) and Jacobi (1991) has demonstrated when mentoring students, this can be evaluated through these four domains:

- Psychological and emotional support
- Degree and career support
- Academic subject knowledge support
- Having a positive role model

Recent research has demonstrated that having a sense of belonging is important for higher education students who are part of underrepresented groups (Strayhorn, 2018). For the purpose of this case study, a sense of connectedness is being defined as a sense of connection and belonging to the university, peer community, and chosen profession (Beauchamp et al., 2022). Due to how the focus ESTeEM programme is not on academic knowledge support, this outcome was not evaluated for the purpose of this study.

It has been documented that individuals who volunteer to be a mentor gain from this experience because acting as a mentor contributes to a positive workplace and is linked with improved job satisfaction and lower rates of burnout (Beheshti, 2019; Fishman, 2021; Jeong et al., 2018). It also leads to promotions and higher salaries which means this can be a win-win activity for both the mentors and mentees within a company (Bierema, 2017; Coates, 2012; Nick et al., 2012). When measuring the impact for the mentors, the focus was on improving their leadership skills as well as interpersonal competencies such as communication and problem-solving, as well as giving back to the next generation of engineers (Banerjee-Batist et al., 2018; Baranik et al., 2010; Bierema, 2017; Coates, 2012; Nyanjom, 2020).

Finally, it should be noted, the university also benefits from ESTeEM although not all of this impact has been measured. When higher education has mentoring programmes that are linked with enterprise partners it facilitates engagement with alumni and philanthropy. This is an opportunity to either reinforce existing relationships or new ones can be developed (Jackson and Meek, 2020). Additionally, by the university providing holistic support and development of their students, including ones from under-represented backgrounds, this will lead to improved retention and student success (Dahlberg and Byars-Winston, 2019; Nora and Crisp, 2007; O'Brian, 2022). All of these benefits enhance the university's reputation since it will be bolstered by both the student and the alumni success (O'Brian, 2022).

3.1 The inaugural year: 2017 – 2018

In this first year, there were thirty-seven students from the full-time programmes in the School of Electrical and Electronic Engineering who volunteered to take part in the four ESTeEM events. The group included four Erasmus Bosnian students who joined ESTeEM for the two events in semester 2 only. Unfortunately, there were no women in the craft practice apprenticeship blocks during that academic year. Feedback was very positive in relation to the experience of all participants and some suggestions for improvement were identified.

3.2 Year 2: 2018-2019

There were changes to the programme for the second iteration of the ESTeEM programme which were based on the feedback from the last cohort. The most notable change was that it was decided to increase the number of events from four to five. Also, the School of Computer Science and the School of Marketing joined ESTeEM, and further companies, who contributed mentors, joined: ESB, MasterCard and SAP. This increased the number of student participants to ninety-four. Again, feedback was very positive in relation to all participants, with no suggestions for improvement identified.

3.3 Year 3: 2019-2020

All elements of the program remained the same, including the student numbers, although Dublin City Council joined ESTeEM as a mentor for this programme. Again, feedback remained very positive.

4 Lessons Learned and Recommendations:

The ESTeEM programme has been a great success in terms of meeting the purpose, aims and ambitions of the programme. However, a review of the operationalisation of the programme is now timely to ensure that we continue to build on the success experienced to date.

The excellence and success of the ESTeEM programme has been acknowledged by the University and externally. This is making other Faculties and Schools consider the introduction of mentoring programmes to assist their students on their learning journey. Experience with the ESTeEM programme to date has demonstrated the need for formal policies regarding mentoring in TU

Dublin. There are no formal policies at present. A policy is required to outline how these programmes are implemented and managed, and to ensure staff resources and financial inputs are utilised effectively. The current lack of policy development in mentoring is leading to a lack of consistency across mentoring initiatives and many activities might not meet best practise guidelines (notwithstanding the fact that the ESTeEm continues to meet best practice guidelines at all times). TU Dublin is not unique in this issue, (see Nora and Crisp, 2009).

The ESTeEM programme is currently managed by one adjunct faculty member. Once formally adopted by the University, the programme would benefit greatly by being placed in the formal organisation structure. This would enable accountability for managing and overseeing ongoing mentoring activities. In addition, the operational issues that need to be managed would be dealt with in a consistent way. Such operational issues include setting up events, attending external events to develop an understanding for international best practise; manage and deliver student and mentor inductions; to manage, monitor and oversee each event and address any issues that emerge quickly and efficiently; promote the ESTeEM programme and recruit students; manage ongoing relationships with industry mentors and their companies; to measure impact and implement informed changes when appropriate; design and deliver ice-breaker events for first time mentors and mentees. Also a dedicated budget for the activities should be developed. This would streamline event management co-ordination activities such as lunches, project management and co-ordination and to improve efficiency of operations.

A specific website for the ESTeEM programme would be beneficial to highlight and share activities across the University and to a wider audience. This would assist with gaining visibility with professional bodies and philanthropy organisations who are focussed on EDI activities.

A consistent and dedicated space to be timetabled for ESTeEM events would enable organisational learning to occur and enable all events to be held on campus. This might involve creating a module descriptor for the programme so that it can be formally timetabled into University systems.

5 Conclusion:

Mentoring, which enhances staff and student success, provides a mechanism for the university to enhance its reputation through the achievements of these individuals (O'Brian, 2020). Additionally, it facilitates the building and reinforcement of relationships and partnerships with enterprise as well as with alumni which also further strengthens the university's reputation. The contributions obtained through these connections will also benefit the university students, staff, and early career researchers (Jackson and Meek, 2020). The ESTeEM programme has been successful in improving retention of female (and other minority genders) students on STEM programmes. This success supports the need to formalise this activity in the university to continue to improve participation of minority groups in higher education as part of a broader EDI initiative.

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A CONCEPTUAL FRAMEWORK FOR TEACHING MACHINE LEARNING FOR ENGINEERS

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ABSTRACT

As machine learning and artificial intelligence become increasingly prevalent in our day-to-day lives, there becomes an even greater need for literacy in machine learning for those outside of the computer science domain. This work proposes a conceptual framework for teaching machine learning to engineering students with the goal of developing the knowledge and skills needed to apply machine learning techniques to engineering problems.

Many machine learning courses in computer science, math, and statistics focus on the theoretical basis of machine learning algorithms and assessment. This framework takes a fundamentally different approach by creating a course structure for machine learning practitioners rather than machine learning developers.

The presented framework breaks machine learning into four fundamental principles that should be used in any machine learning solution: data (what information we can use to develop our solution), task (what we are trying to accomplish with our solution),

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algorithms (what computational models we are using to create our solution), and assessment (how we are measuring the success of our solution). To teach this framework, the structure of the course includes creating concept maps of the four fundamental principles and relevant topics, completing coding tutorials, and creating in-class presentations that use and apply the four fundamental principles.

The paper will present the need for machine learning and artificial intelligence education within engineering, the framework and supporting learning theory, suggested activities for implementation, and lessons learned from the implementation of this framework in a 1-credit course for engineering students.

1 INTRODUCTION

Machine learning and artificial intelligence (AI) are becoming increasingly embedded in the industries that drive our world -- including healthcare, energy, infrastructure, marketing, and education. The World Economic Forum's Future of Jobs Report 2020 demonstrates the growth of AI through its survey of hundreds of companies in 26 countries. Its list of 20 emerging job roles includes titles such as data analysts and scientists, AI and machine learning specialists, big data specialists, and digital transformation specialists. The report also illustrates the importance of engineers as society make this transformation into new jobs and roles; jobs traditionally in the "engineering" sector will soon shuffle into new emerging industry sectors including "cloud computing" and "data and AI". Although these spaces will be shared by those in sectors such as information technology, engineers will play an integral role in the emergence of these new areas of industry (World Economic Forum 2020). To support future engineers entering these roles, there is a greater need for structured spaces for learning about artificial intelligence and machine learning in engineering classroom settings.

A variety of engineering programs have begun offering machine learning courses, but there has been little published about how machine learning for engineers should look different from other computer science-focused machine learning courses. Engineering and computer science courses in machine learning should have different goals and therefore different structures; rather than developing expertise in the theoretical basis of machine learning algorithms, engineering courses in machine learning should be focused on developing practical and applied machine learning knowledge and skills. To fill this need, a conceptual framework for teaching machine learning to engineers was created. This publication shares the research basis for the conceptual framework and its creation, introduces the conceptual framework, describes the implementation of the framework in a one-credit course, and shares lessons learned from implementation.

2 THE BASIS FOR A CONCEPTUAL FRAMEWORK

Whereas computer science courses in machine learning help students develop expertise through a deep exploration of theory and practice, we propose that engineering courses in machine learning should serve as a "shortcut" to developing expert-like thinking in the topic. Rather than serving as theoretical experts in machine learning, engineers serve as practical experts in machine learning. To support this practical development, the conceptual framework was designed considering learning sciences research about the process of building expert-like thinking. In the seminal report *How People Learn*, three components of building expert-like thinking were identified: 1) gaining a foundation of factual knowledge, 2) understanding these facts and ideas in the context of a conceptual framework, and 3) organizing knowledge in ways that facilitate retrieval and application (National Research Council 1999). All three of these components are important in helping learners develop competency in machine learning; they must gain a foundation in the key principles of machine learning, but they also must have a conceptual framework that helps them organize those ideas and apply them to new situations. This does not mean that students take the course to become machine learning experts. Rather, they take the course to structure and organize their fundamental knowledge like an expert so they can draw on that knowledge in practice.

The factual knowledge and means of facilitating retrieval and application can be adjusted depending on the context of the course, instructor, and students, but the proposed conceptual framework serves as a unified grounding for teaching and learning machine learning as engineers.

3 METHODOLOGY

The conceptual framework was developed by reviewing existing textbooks in machine learning (Bishop and Nasser 2006; Witten and Frank 2002; Mohri et al. 2018; Alpaydin 2020; Shalev-Shwartz and Ben-David 2014) and identifying popular concepts and topics across the textbooks. These topics were then grouped using an inductive coding approach with the goal of creating a conceptual framework for teaching and learning of machine learning for engineering students. The developed conceptual framework was then implemented in a pilot course, and each of the authors (one instructor and one student) provided perspective and insight on the use of the framework within the course.

4 THE DEVELOPED CONCEPTUAL FRAMEWORK

Through the analysis of the various machine learning textbooks, four key fundamental principles of machine learning were identified: data, tasks, algorithms, and assessment. Table 1 presents the four fundamental principles of the conceptual framework and their definitions, as well as example concepts from the textbooks that apply to each of the fundamental principles.

In the context of the three components of building expert-like thinking introduced in Section 2, this framework supports both the gaining of factual knowledge (such as the concepts listed in the table) and the organization of that knowledge for the purpose of application.

For example, one engineering application of machine learning is design optimization. One of the goals of the framework is to help students bridge the gap between what they are learning in class and a specific application. Using the framework, a student in the course could review a paper that discusses how neural networks have been used to optimize turbine blade aerodynamics (Zhang and Janeway 2022). Although the work presented includes significant technical depth, the framework can still be applied by someone new to the field of machine learning to summarize the study and connect their factual knowledge from class to a specific application. *Data* from the study includes 20 quantitative blade design parameters. The *task* being performed is regression to predict isentropic efficiency and power output from the blade design parameters. The *algorithm* chosen was an artificial neural network trained with various blade designs with known performance, and the resulting model was assessed by comparing the known performance metrics to the predicted performance metrics using evaluation error percentages. Although a student may not understand many of the technical details of the paper, they are able to understand the goal of the work and if that goal was met. On the learning front, they are further strengthening their understanding of factual knowledge by applying their conceptual framework to a practical application, ultimately building expert-like thinking of the subject.

Table 1. The Proposed Conceptual Framework for Teaching Machine Learning for Engineers. The framework consists of four fundamental principles.

Fundamental principle	Definition	Example concepts
Data	The characteristics of data and the processes used to utilize that data for machine learning processes	Types of data: numerical, categorical, time series, text Data vocabulary: targets, classes, and features
Tasks	The goal of the machine learning solution	Overarching task categories: supervised, unsupervised, semi-supervised learning Specific tasks: classification, regression, clustering, association analysis
Algorithms	The mathematical, statistical, and/or computational approach to completing the machine learning task	Example algorithms: support vector machines, decision trees, logistic regression, neural networks, a priori, k-nearest neighbors, DBSCAN
Assessment	Metrics for quantitatively assessing the ability of the machine learning model to complete the task	Example assessment metrics: confusion matrices, accuracy, recall, precision, mean absolute error, lift, support, Davies-Bouldin Index

5 EXAMPLE IMPLEMENTATION OF THE FRAMEWORK IN A COURSE

The conceptual framework was applied to a 1-credit machine learning elective course for junior and senior-level students majoring in Integrated Engineering. Students came from two separate programs within the same department. One of the programs is a work-based engineering program where students spend their last four semesters of the program working full-time in engineering co-ops while taking their courses in the evening. The second program is a project-based engineering program where students work on industry-sponsored projects.

The information presented in this section serves as a single example of how the framework could be implemented in a course; others looking to implement the framework should consider the concepts and activities that best fit their student and program needs.

5.1 Structure of the Course

This course was taught using a flipped classroom approach, meaning students watched videos about the course content before coming to class, and class time was used for activities and discussion. The class size was 12 students.

Table 2. Modules and example topics introduced in a 1-Credit Implementation of the framework. The first module introduces the conceptual framework that will be used in the course, as well as basic concepts related to data and tasks. Modules 2-5 each dive deeper into the 4 tasks and cover the four fundamental principles in the context of each of the tasks. The final module is a review of concepts covered.

Module	Topics introduced
1. Introduction to the Fundamental Principles	Machine learning, data, tasks, algorithms, assessment, target, features, types of data (numerical, categorical, time series, text), supervised and unsupervised tasks, classification, regression, clustering, association analysis
2. Classification	Classes, training set, testing set, balanced datasets, unbalanced datasets, oversampling, undersampling, support vector machines, neural networks, dummy classifiers, confusion matrices, accuracy, precision, recall, F1 score
3. Regression	Underfitting, overfitting, linear regression, polynomial regression, Ridge/LASSO, dummy regressors, mean absolute error, mean squared error, root mean squared error, R squared
4. Clustering	Dimensionality reduction, principal component analysis, centroid-based clustering, density-based clustering, hierarchical clustering, k-means clustering, DBSCAN clustering, agglomerative clustering, internal evaluation, external evaluation, Davies-Bouldin Index

5. Association Analysis	Association rules, antecedent, consequent, a priori algorithm, FP growth algorithm, support, confidence, and lift
6. Review and Wrap-Up	Review of previously covered topics

5.2 Example Course Activities

Throughout the course, seven main deliverables were introduced. Four of the deliverables were due weekly and served as formative assessment: the concept map activity, the coding tutorials, the learning journals, and class engagement. Three of the deliverables were due at the end of the course and served as summative assessment: the in-class presentation, the deep learning activity, and the final verbal exam. The formative assessments focused on the first component of developing expert-like thinking: gaining a foundation of factual knowledge. The summative assessments focused on the third component of developing expert-like thinking: organizing knowledge in ways that facilitate retrieval and application. The four fundamental principles were used in all aspects of the course to promote the second component of developing expert-like thinking: understanding knowledge in the context of a conceptual framework.

<u>Concept Map Activity:</u> Each week, 10- to 20-minute videos were posted covering the topics presented in Table 2. To show engagement with the videos, students were asked to put each of the topics on a concept map – a visual representation of how ideas are connected. They were instructed to include descriptions and/or images of the required topics, questions that they had, and at least 2 concepts that were *not* covered in the videos. For example, during the classification module, all students were instructed to add the topics in Table 2, but they were also given additional topic ideas such as other algorithms (random forest, K-Nearest neighbors), other performance metrics (log loss, ROC AUC), or other considerations of classification models (binary vs. multi-class vs. multi-label); students could choose to add these ideas as their additional topics or identify their own. The concept map was designed to facilitate the organization of the factual knowledge that students were gaining throughout the course. It also encouraged self-directed learning by requiring that students add concepts other than the ones covered in the videos.

<u>Coding Tutorials:</u> During the course, students completed two coding tutorials in Python. For the first activity, students created a classification algorithm that predicted part failure using a variety of quantitative features. For the second activity, students created a clustering algorithm that grouped unlabelled hand-written images into clusters; they assessed the clustering algorithm by using external evaluation to see how often images of the same number were clustered together. These tutorials were created by the author using Replit, a collaborative web-based integrated development environment. Because this course is focused on using machine learning as a tool rather than developing coding expertise, all relevant functions were provided to students to use. In addition, students could access fully functioning code from the instructor if they got stuck. Rather than being assessed on their ability to write code, they were assessed on their responses to questions that were embedded

in the activities. These questions were related to each of the fundamental principles. Example questions included “What type of data are each of the input features?”, “How does your code account for the fact that there are more samples that do not fail than samples that fail?”, and “Which of the models perform the best? Use your assessment results as evidence.”

Learning Journals: Each week, students were given a prompt to reflect on in 1-2 paragraphs. These prompts varied in topics including reflection on how they practiced self-directed learning while working on the coding tutorials, ethical considerations of machine learning, and how they see machine learning applying to their area of engineering.

Class Engagement: Because content was delivered during the videos that students watched outside of class, in-class time was used for activities, discussion, and in-class presentations. Students were assessed on their participation in these activities. If they were not able to attend class, they watched a recording of the class and submitted a reflection of what their takeaways were to demonstrate engagement with the material.

In-Class Presentation: One of the additional goals when developing the pilot course was giving students the chance to explore relevant and current applications of machine learning. Students worked in groups to create a presentation and corresponding activity about a topic of their choice. Each group was given 25 minutes during class time to share their work and lead discussion.

Deep Learning Activity: The deep learning activity was a summative assessment where students were asked to connect the course concepts to an engineering application of machine learning. They could write a paper or create a video about their application, and they were assessed on four criteria: 1) their ability to identify and describe an engineering application of machine learning, 2) their ability to apply the four fundamental principles and course concepts to their application, 3) their ability to show technical depth beyond what was covered in the course, and 4) their professional communication (including citing relevant academic sources).

Final Verbal Exam: The final verbal exam was a final opportunity for the instructor and students to discuss the course concepts one-on-one. Students were instructed to come with an engineering application of machine learning, and the instructor could ask any question about the application related to the topics included in Table 2. Many students chose the same application that they covered in their deep learning activity, but the verbal exam allowed for a space where the instructor could further probe student understanding of the course concepts and help clarify any final misconceptions.

6 STUDENT PERSPECTIVE

The narrative below is written by a student who was enrolled in the course.

I initially took this course because I didn’t know what machine learning was or how to use it. Still, as an engineering student who loves building my toolbelt, I felt like it *would be a great opportunity to learn about a topic outside of my mechanical engineering focus so that I could bring more value as a future engineer. After taking the course, I gained confidence in applying machine learning algorithms as learned through the coding tutorials, identifying scenarios where machine learning algorithms add value to a project, and selecting appropriate machine learning algorithms based on my data and goal.*

As part of my program, I have the opportunity to work full-time in industry as an engineer while completing coursework towards my degree. At my current company, a defense contractor in Southern California, we had a data collection device that utilizes a regression model to predict a characteristic of our products, but it wasn't working well. Through this course, with the knowledge I gained, I was able to troubleshoot the issue with a recently hired data engineer. With my expertise in the product and the value of the project, and the data engineer's technical perspective, I was able to utilize the fundamental principles learned in this course as the foundation to ask him the right questions and provide him with the required information for us to successfully troubleshoot and improve the machine learning model. It was a great feeling to see the model finally produce more accurate results and to know that my education immediately applied to a real problem, allowing me to add value to my company.

7 INSTRUCTOR PERSPECTIVE

The instructor offers the following takeaways from implementing the framework:

1. Even if a student is choosing to take the course, they may not have any background in machine learning. In their reflections, many students noted that they came into the class knowing little to nothing about machine learning. There is benefit in spending sufficient time at the beginning of the course to help the class develop a shared definition of machine learning (while recognizing that even experts have various perceptions of what is and is not machine learning).
2. Students appreciated the open-source approach to coding. With an abundance of code available on the internet, being able to understand and adapt someone else's code can be just as beneficial of a skill as writing your own code. Although writing code is a valuable skill, the coding activities in this course had a fundamentally different goal; they served as a space for students to better understand how the fundamental principles and other course concepts are integrated into a coding solution in an application that is relatively simple, but still relevant.
3. Vocabulary can be a challenge, so it is important to keep discussion open about how the instructor does and does not define terms. For example, words like "task", "precision", and "unsupervised learning" have very specific meanings in the context of machine learning, but students may come in with other ideas of what these words mean. "Precision" in the context of classification assessment refers to the proportion of positive cases that were predicted to be positive. However, students may hear "precision" and think about the consistency of an algorithm more generally.

4. Students left with positive feelings about their ability to understand and work with machine learning tools and applications. Activities like the concept map and the deep learning activity helped them realize that there is more to be learned, but they remained confident in their ability to ask the right questions and navigate engineering applications of machine learning.

8 SUMMARY

This paper presented a conceptual framework for teaching machine learning to engineering students. The development of the framework combined theory and practice by 1) employing learning theory about gaining expert-like thinking practices to design the structure of the course and 2) analyzing existing machine learning courses and textbooks to determine the content that should be covered. The conceptual framework included four fundamental principles: data, tasks, algorithms, and assessment. All course concepts and activities were framed around these fundamental principles. This helped students develop expert-like thinking about machine learning topics and an ability to understand, discuss, and work with engineering applications of machine learning.

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Engagement in technical student-run organizations: How does this effect the students' well-being and what does it mean to the future of education?

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ABSTRACT

Loneliness among Norwegian students has never been higher than after the Covid-19 pandemic (Lervåg et al. 2022). In recent surveys, over 50% of Norwegian students report they felt troubled by loneliness (Lervåg 2022, Tekna 2022). One article written by a student representative implies that loneliness may be counteracted if engineering students participate in student organizations, and that the universities needs to facilitate for that (Nitschke 2022). Engineering students worldwide engage in student-run organizations (SRO) where they design, develop, and build technical solutions (Li et al. 2023, Dol 2016). At the Norwegian University of Science and Technology (NTNU) those student organizations are referred to as *technical student-run organizations* (TSRO). This study investigates what it means to be a part of a TSRO. The following three questions are asked: 1) How does it affect the students experienced well-being? 2) How does it shape their views on education? 3) What do they think are the benefits from participating

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in a TSRO? This study makes use of in-depth interviews, think-out-loud protocols, and the UCLA loneliness scale. Eleven engineering students from NTNU have been respondents for this study. They are all associated with different TSROs at NTNU. This study might give new insight to important factors of the student well-being after the COVID-19 pandemic, and how the COVID-19 pandemic has impacted our students' psychological conditions. Is there a potential in the TSROs that has not yet been unleashed?

1 INTRODUCTION

1.1 Loneliness amongst students – a worldwide problem

New surveys[2] show that loneliness among full-time students in Norway has never been higher. As many as 60% of students who attend their first years of studies have at times felt lonely (Lervåg et al., 2022). In a second survey[3], the percentage of engineering students feeling lonely is reduced to 51%, and therefore less than the national numbers (Tekna 2021). 53% of the engineering students from the second survey said they were part of a volunteering organization, which could include student-run organizations (SRO). From these surveys, it is implied engineering students are experiencing being less lonely than students from other study programs, and does they engagement in a volunteer organization impact this?

Loneliness is a complex and multifaceted emotional state that arises from a perceived deficiency in social relationships. It is often characterized by a sense of isolation, a lack of companionship, and a feeling of being disconnected from others. Research has shown that loneliness can have significant negative effects on physical and mental health. As such, it is important to recognize and address loneliness as a public health concern and to develop initiatives that can help individuals build social connections and maintain meaning. Students especially stand out as one of the loneliest groups in the society in the post COVID-19 surveys.

Today's national measures of handling the increasing number of lonely students are similar to global approaches. Measures today include student counselling, psychological services, social events, online discussion groups and the establishment of student canteens and meeting rooms (Sivertsen et al. 2021). However, there is still a need to continue working on finding good solutions to support students' well-being and social needs, especially considering the increasing loneliness among students (Hysing et al. 2020; Sivertsen 2022). Several surveys from 2021 have increasing numbers of students feeling lonely between the years of 2018-2021 (Sivertsen et al. 2022). The COVID-19 pandemic was a challenge for many of the local initiatives at campuses in Norway. Many of the universities and colleges have problems in terms of 1) less student attendance in physical lectures 2) less students chose to spend time on university campus, and 3) the

[2] Out of 169.527 Norwegian full-time students, 59.544 students replied to the survey. The survey was conducted between 6th of February to 19th of April 2022 by Norwegian Institute of Public Health.

[3] The union Tekna (Engineering students and engineers are members) have distributed surveys to the students in 2021 and 2022 about the students experienced well-fare. It was distributed to 14.000 engineering students with 10.480 responses.

SROs and the local university organizers are struggling with low attendance for events and low student recruitment for extracurricular activities (ECA).

A large percentage of students at NTNU engage in ECAs, and there are a total of 132 officially registered SROs across the three university campuses. Eighteen of these SROs primarily engage engineering students, and the activities revolve around engineering practices. These organizations call themselves technical student-run organizations (TSRO), but are other places referred to as student teams. There are also several ECA initiatives at NTNU initiated, facilitated and/or led by university employees. Engage - Centre for Engaged Education through Entrepreneurship[4] have six thousand students participating in ECA from mainly NTNU and Nord university every year. Such initiatives include Spark* NTNU[5], Boost Henne[6], workshops, competitions, and summer schools.

TSROs are mostly student-led and based on voluntary work. Most of the TSROs in Norway do not offer salaries or ECTS from the university, but nonetheless, students may choose to spend up to 60 hours each week working in their affiliated organization. A previous study (Sivertsen et al. 2023), describes what the students gain from innovation competences when participating in SROS. All the respondents had two to seven different positions over their study years in a range of SROs and had a lot of learning outcomes from their experience. Most of them joined with a motivation to make new friends.

Previous studies examine and summarizes the benefits of the jungle of ECA (Bartkus et al. 2012), and for this paper all ECAs, SROs and TSROs can be described as “out-of-class experiences” (Nelson et al. 2002). In terms of the TSROs, there has not yet been conducted a study on the effects on students experience in terms of well-being. Berg et al. mentions how first year engineering students have opportunities to engage themselves in these student organizations when entering higher education for the first time (Berg et al. 2022).

Based on the above, the following three research questions are asked in this paper: 1) How does it affect the students experienced well-being? 2) How does it shape their views on education? 3) What do they think are the benefits from participating in a TSRO?

2 METHOD

2.1 Research design

This study employs qualitative research methods since the research questions are asking “how”-questions to investigate the phenomenon in-depth (Yin 2015). Interviews with students in TSROs are deemed appropriate for the qualitative inquiry, and several

[4] Engage - Centre of Excellence in Entrepreneurship Education work to increase the number of students in Norway and around the world with entrepreneurial skills and the mindset to become change agents for the better. Located at NTNU and Nord university.

[5] Spark NTNU a free peer mentoring service for students with a business idea, or who want to be part of a start-up company.

[6] Boost Henne free events for students. The events helps to engage and motivate more female students to explore entrepreneurship and invest in their own ideas.

techniques are combined in the interviews. The in-depth-interviews with followed a semi structured protocol and make use of a think-out-loud protocol to facilitate the data collection process (Ericsson et al. 1998). The think-out-loud protocol includes the revised UCLA loneliness scale where respondents self-report current loneliness and emotional states (Russell et al. 1980). The think-out-loud protocol furthermore have some questions from the two surveys done by SSB and Tekna (Lervåg et al. 2022; Tekna 2022).

2.2 Participant selection and data collection

Eleven TSROs from the NTNU were selected for this study. There are in total 132 SROs or other ECA at NTNU, of which 18 are TSROs[7]. These 18 TSRO include students from around twenty study programs, making the TSRO teams multidisciplinary. The reason for researching TSROs is that in a recent study (Sivertsen et al. 2023), the students express a high degree of psychological ownership to their work in the TSROs, creativity, problem solving, communication skills and their domain is closer linked to their studies – which from a study program perspective can create opportunities for collaborations of some sort. One student from each of the eleven TSROs were invited for a qualitative interview. The interviews lasted from about one hour to more than two hours each. The interviews were audio recorded, and the author also took personal notes from the conversations and also documented observations.

2.3 Data analysis

The data analysis departed from a set of themes related to loneliness – based on the topics in the think-out-protocol – for a thematic analysis of the qualitative data. However, the data revealed unexpected insights into well-being rather than only loneliness as such. Therefore, an abductive analysis approach (cf. Sætre and Van de Ven 2021) was done, going back-and-forth between the data and concepts (loneliness, well-being, etc.) from the literature. Therefore, the content and structure of the analysis results were guided by the research data collected from recorded audio, written notes, and observations during the interviews.

2.4 Ethical considerations

The study with data collection, interview guide, research plan and data management are approved by Sikt[8] and ethical considerations are being taken. The data will be anonymous. This data is considered health information and is therefore even more important to not disclose the respondents' identities.

3 RESULTS

3.1 Initial findings

The respondents have all participated in a TSRO from 7,5 months up to almost three years and are currently active members. They come from different places in Norway

[7] The 18 TSROs are Cogito NTNU, DNV GL Fuel Fighter, Hackerspace NTNU, Ingeniører Uten Grenser, Makerspace Gjøvik, Start Gjøvik, Orbit NTNU, Start NTNU, Start Ålesund, Propulse NTNU, Programvareverkstedet (PVV), Shift Hyperloop, Omega verksted, Vortex NTNU, Revolve - Formula Student, Ascend - NTNU's team in the International Aerial Robotics Competition, Spark NTNU.

[8] At Norwegian Agency for Shared Services in Education and Research the Norwegian Centre for Research Data is located. They approve research projects in terms of ethics, data management plans and important factors for the individual study.

and chose NTNU for various reasons. Most of them because their father or siblings have studied at NTNU, and all the respondents mentioned that NTNU is well-known for an active and social student atmosphere with many activities. Only one student had his sights for a particular TSRO, he later joined, already 3 years before he started his studies. It seems to be more common for the students to pick the student organization based on random factors such as 1) what day the TSRO had recruitment stands on campus 2) which students the respondents met during the initial few weeks in the start of a degree and 3) what organizations those new acquaintances picked. What organizations they become a part of shape their identity. They wear clothing with logos from the TSRO when they go to lectures and hang out at campus. They also identify as “one of us” and have a perception of what "the other" is like. The respondents do not at present time self-estimate that they are lonely – overall the results from the interviews, think-out-loud protocol and the UCLA sheet gives the impression the students are overall quite “unlonely”. This group of respondents are far away from the national loneliness numbers amongst students. In fact, the students rate themselves as less lonely than the national average by far. When we talk about loneliness, the respondents’ express worries that hasn’t happened yet.

3.2 Becoming a student – scary and big auditoriums

Some of the respondents had a tough time becoming students. Because the respondents for this study are in their second and third year of studies, most lecturers were taught in digital platforms because of the COVID-19 pandemic. The respondents did not make many friends in the first semester of studies, and they did not feel like they knew other students well enough to call them “friends”. During the interviews the respondents often describe other students from their study program or TSRO as “acquaintances” and have a high threshold for calling relationships friends.

From an interview with a respondent (respondent A) that wasn’t a part of a student initiative her first study year, she described how she became passive during and after the Covid-19 pandemic, and how it affected her last year of high-school and first year of higher education. She didn’t feel like being active or taking part in anything. The responded studied full-time and had a part-time job, but felt lonely at the university campus:

"When it rained a lot, I struggled to get up and go to classes. Especially since I could follow along digitally and didn't know anyone else in the class."

The respondent, similar to all the respondents in this study, goes to lectures in big auditoriums with several hundred students and finds it scary if they don’t know any one there.

Since then, the respondent has become part of a TSRO, and have been so for almost a full year by the time of the interview. She will continue with this for at least another year. She is moving to a position with more responsibility. At the time she felt lonely at the start of her studies she often went home to her parents to stay and meet her at-the-time boyfriend. That made her feel better then. Now, she is not in any romantic relationship. Her result from the interviews indicates she is not at present time expressing feelings of loneliness. She is rather very happy and content with her current life situation, is invited to parties and have two good friends she is living with that she tells is important to her. She spends a about 15 hours every week on her work in the TSRO, and around 30 hours studying.

3.3 Best friends – the best support

The respondent (respondent B) that scores to be *least l*onely from results using the UCLA scale, explains in his interview what he is most worried about. In general, he lives with, amongst others, his best friend from high school. He expresses that the best friend's role is extremely supportive. The two of them have regular activities together several days and evenings each week. When the respondent was filling in the UCLA sheet, he addressed the question "I do not feel alone" with saying:

> *"I am just worried in case my best friend gets a girlfriend. Then I might have to spend a lot of time by myself and get lonely".*

His best friend is not a part of the TSRO. He spent around 25 hours every week at the location of the TSRO, and the weeks leading up to the interview he spent 45 hours at the TSRO. Sometimes he is there and does study related work, but most of the time he works in the TSRO and hang out with other members. In the fall he will take on more responsibilities and go from a team member to become a technical team leader.

3.4 Overworked – expectations across the board!

The respondents are struggling more with feeling of being overworked and have psychological effects of this. This applies the respondents who are in leader positions and have studies with a high degree of difficulty. Attempting to achieve high academic results and at the same time following up all students in the TSRO and all inquiries from collaborations and other stake holders takes a toll. The respondents describe how they actively distance themselves from the TSROs and often solve this by traveling home to family, and/or going to enjoy the outdoors. Some of the respondents share how they struggle to complete all their study courses in normal time and need to re-take their exams on a later point. They are most motivated to spend their time on activities that relates to results that effects the other students and stakeholders in the TSRO. Their own individual performance in their study is taking a backseat. It seems like not all students are have this problem, a few are skilled at time management and have good habits to get everything done in time and therefor have good academic results and perform well and spend a lot of time in the TSRO. It seems the good academic results are easier to achieve if the tasks in the TSRO are similar to their study program and transferable to the courses. There were no questions regarding academic results in the interview guide, but the students chose to talk about it in the interview setting.

3.5 It's not for everyone – because you might not get accepted

Being part of a particular SRO, or TSRO, is not always available for all students. The respondents are describing the recruitment processes, and how some of the organizations have demands particular prior experience, large work capacity, and expectations that the members need to spend 10, 15, 30, up to 60 hours each week over the coming year. A lot of students are declined in the process of recruitment for an

SRO that they are applying to. Some of the TSRO, nevertheless, have fewer applicants than others.

3.6 Building a social community

One of the TSROs launched their new "project" this spring. They had been working on it for seven months and 85 people were present at the event. Several of the students were up on stage presenting this. 53 students from 24 different study programs had been part in making this, and it had been over 25 000 working hours into the project. The student leader of the TSRO said this:

> *"It's a place to be curious. It's a lot of kind people and a place to make friendships. Our job is to connect likeminded students to challenge themselves and see what's possible. There are often long days and sometimes problems. But always pun and jokes*".

During the event, the students looked proud and grouped together to take pictures with business partners, friends, and family next to the new "product". Being part of a SRO enables the student to build connections with peers who share similar interests, and to engage in collaborative problem-solving and team-building activities.

The social aspect can be a trigger for the students and motivate them to spend time in the organization, some of them join to make new friends, and some of them realize after some time the social benefits. Several of them point out that working together in a team is a positive experience and being able to progress and make something much better than if they only did it themselves as a hobby. One of the students tells us about the difference between the TSRO work comparing it to his studies. He says that the study program has a lot of independent work, and they sometimes help each other out with assignments, but large teams of more than three students with a large organization with over 50 students working together is very different. This could be an interesting challenge to educators of engineering education - are we able to facilitate larger challenges or exercises for large groups?

4 CONCLUDING DISCUSSION

This study has investigated what it means to be a part of a TSRO, asking the following three questions: 1) How does it affect the students experienced well-being? 2) How does it shape their views on education? 3) What do they think are the benefits from participating in a TSRO? Although this study started out with a focus on well-being focusing on loneliness, the abductive research process shifted the focus over to well-being in a broader sense. To conclude, the respondents do not directly relate TSROs as factors for not being lonely. Therefore, it is in this study challenging to conclude anything about the TSROs role in reducing the respondents feeling of loneliness. For a later study, a research design that enables a control group of students that is not part of the TSRO but having a similar study program and background would be a way to try to measure this. However, this study pinpoints several ways in which TSROs relate to students' well-being. For example, this study suggests that ECAs can have a positive impact on students' social connectedness and sense of belonging, which may help to reduce feelings of loneliness and isolation.

Several questions for further research emerge. For instance, the sometimes extensive work required from students in a TSRO may have negative consequences. What about the students that feel overworked and worst case, get a burnout? A focus on overwork and burnouts is one suggestion for further research. However, this study has also pinpointed that there are several benefits of involving in a TSRO, but many students may not be admitted into the organizations. Thus, another topic for further research that emerges from this study is how the benefits of ECAs in general, and TSROs in particular, may be scaled to reach and engage even more students. A third topic for further research is how students' engagement in ECAs may aid and even integrate with curricular teaching and learning. For instance, ECAs offer an arena where students get to know their peers, and perhaps may we as educators employ similar approaches to create a social community in our classrooms? Can a stronger social community motivate more students to attend curricular initiatives in-person?

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Becoming an expert in in soft robotics in one week and beyond!

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ABSTRACT

The Athens network of technological institutions and universities offers students international exchange experiences through intensive specialization courses during a brief period. Yet, it is challenging to effectively explain complex research topics to students in only one week, while offering at the same time self-paced learning perspectives instead of absorbing expert lectures as a passive student. Furthermore, students often experience a knowledge gap with the 'international experts' they are consulting, which hinders vivant exchange of ideas during discussions. In this context, we report our experiences of a newly designed crash course within the field of soft robotics that was offered to a group of international students. Our approach is a concept of combining flipped teaching, peer learning and student empowerment within engineering sciences. A scenario is elaborated and finetuned in which students experience a set of (semi-)self-paced activities and achieve the learning goals in a (semi-)independent way. This includes a preparatory activity and, on the spot, (re-)active learning through peer-discussion on emerging topics in the field of soft robotics and collaborative creation of a simple, functional, soft robot. The daily progress of the research topic and design challenge is checked, and the progression of the associated expertise is mapped. Students especially appreciate the positive atmosphere with a focus on a growth-mindset, the teamwork experience, and the opportunity to discuss on an expert level. The message we wish to pass is that our transferrable educational setup generates strong learning dynamics that radiates out to the students and the supporting didactic team.

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1 INTRODUCTION

The ATHENS program enables students to attend for one week a 3 ECTS course, offered by network universities, facilitating the exchanges of students coming from European technological institutions. As such, students experience being immersed in another educational system. The Faculty of Engineering Science of KU Leuven organizes several ATHENS courses each year and educational developers explore new opportunities to incorporate active learning formats, with a prime focus on blended learning. We refer to this as virtual mobility, in which the addition of blended pathways to a short-term physical mobility trajectory enables extra learning opportunities.

In this context we accepted the educational challenge to introduce engineering students into the field of soft robotics, which is a subfield of robotics that focuses on the design, control, and fabrication of robots composed of compliant materials, instead of rigid links (Rus and Tolley, 2015). It is challenging to design and implement a new course in such rapidly evolving fields of engineering sciences, especially if no overview textbooks are directly available and frontiers of current knowledge are fragmented across several European research groups, risking an overload of details and loss of knowledge links. By simply inviting senior scientists that overwhelm students with a series of standard, condensed lectures, the desired vivid exchange of ideas between students and invited lecturers is absent, which contrast our intention of integrating active learning formats as much as possible. Qualitative interviews of similar rigid setups indicate that students perceive an inequality of knowledge with respect to the experts, resulting in a discomfort to actively contribute during discussion moments and a fear of embarrassment when asking questions (e.g., Forbrig et al., 2022).

Forbrig et al. (2022) radically reorganized their course design by focusing on the creation of a student-oriented learning arrangement to gain the needed theoretical knowledge of a newly introduced study field within a limited period (a so-called one-week setup). A key aspect is keeping the commitment of invited experts to a minimum yet maximize their indirect contributions. Their concept is the basis of the practice experience elaborated here, with a higher focus on problem- and project-based learning (De Graaf and Kolmos, 2007). Based on these conditions, we designed an introductory course to bring students rapidly to a more advanced level of capturing the research and application frontiers in soft robotics, interconnected with the expertise present at KU Leuven and within Europe. As no comparable course format is available, we wish to share our insights of our newly designed setup. Here we report our design process, the experience and our intentions for further improvement.

2 OBJECTIVES AND METHODOLOGY

2.1 Intended learning goals

By introducing soft materials in the design, soft robots become safe in interaction with humans and other delicate objects. However, their analysis does not fit the traditional hard robotic framework. In this course, students receive a broad introduction to the field for soft robotics and three learning goals are put forward:

1. students acquire the necessary skills and knowledge to create self-made inflatable soft robots by problem definition and specification (goal 1);
2. students understand how to design, fabricate and control these new types of robots, plus applications in various scenarios (goal 2);
3. students are familiar with state-of-the-art research topics in the soft robotics domain and are open for in-depth discussion and create new insights (goal 3).

2.2 Student group and networks of European technological institutions

In the framework of the CLUSTER network (see https://cluster.org/), the Faculty of Engineering Science at KU Leuven intends to transform several spearhead courses to enable short-term mobility possibilities between CLUSTER partners. By adding an additional blended pathway to physical mobility, we anticipate increasing the learning opportunities for students who follow courses within this network, thus creating extra (virtual) layers in the available learning spaces (e.g., Ellis and Goodyear, 2016). However, there is still a need for an elaborated didactic framework, especially for activities that are commonly used within engineering sciences and including aspects of international and intercultural learning and collaboration. This elaborated case can provide input and inspiration for further expansion of the virtual mobility concept.
The ATHENS program is aimed at carrying out intensive specialization courses during defined short periods (see http://athensnetwork.eu/athens-programme.html), enabling students to attend courses offered by the network, and have a great potential to be incorporated in a virtual mobility context. These ATHENS weeks enable students from different institutions to take short courses of a high scientific level and to mix with students of different nationalities and backgrounds. This learning experience at other European institutes, in many cases, gives students the desire to conduct studies of a longer duration (MSc and PhD levels) at an institution different from their home institution. Each ATHENS week includes both 30 hours of scientific activities as well as 10-15 hours of 'European Dimension' social and cultural events, reflecting a 2 to 3 ECTS credit course and includes an examination organised by the host institution. In total, 22 students coming from 7 network technological universities, subscribed for the offered course in soft robotics (Figure 1). All these engineering students are either in the end phase of their bachelor program or are studying at a master level and consequently have limited or no prior knowledge on soft robotics.

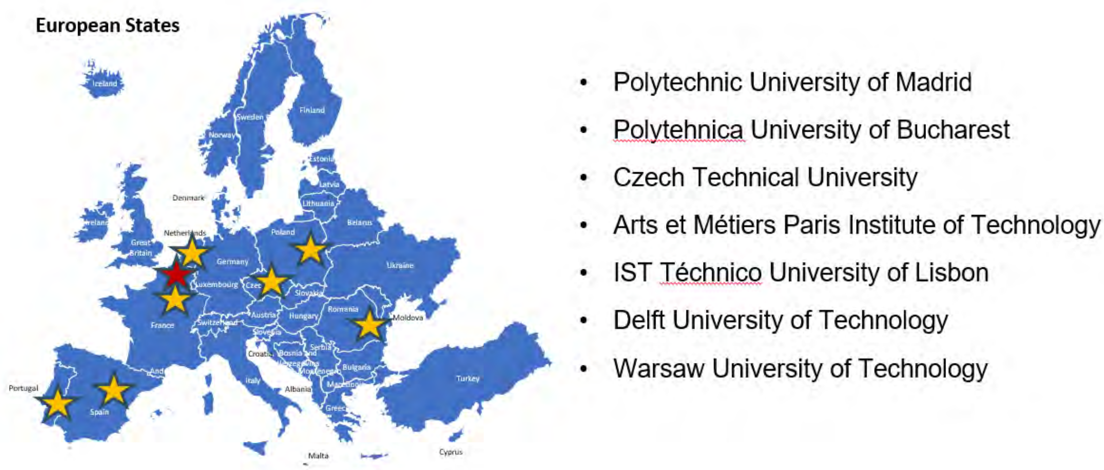

Figure 1: Map with the organizing ATHENS university in red (KU Leuven course in soft robotics) and student's ATHENS home universities in yellow.

2.3 Educational approach

Attention is given to the qualifying (knowledge buildup), socializing (interpersonal collaboration within the discipline) and subjectivizing (development as a person) dimensions of learning, directly focusing on the adequate development of their disciplinary future self as an engineer. Emphasis is on the didactic aspects within an international and intercultural context, which will turn an ATHENS course into a student-focused format with higher higher-order thinking skills (Anderson and Krathwohl, 2001). Our focus is on inquiry (learning by finding out), collaboration through peer-discussion and collaborative creation (learning by doing). In our setup, students rapidly pass the stage of passive listening, which often merely focusses on aspects of remembering and understanding of theoretical facts and applications, and start an educational journey towards analyzing, evaluating, and creating by placing theoretical elements of soft robotics and methodologic approaches into a coherent story. Groupwork in a collaborative learning space is considered as one of the most effective learning environments for these purposes, considering our learning activity-centered analysis and design (Goodyear et al., 2021). As such, groupwork by discussion and co-creation is the dominant activity students executed in the collaborative rooms (Figure 2).

pre-course assignment 24/02 to 10/03		ATHENS WEEK Mon. 13/03	Tue. 14/03	Wed. 15/03	Thu. 16/03	Fri. 17/03	post-course assignment 18/03 to 31/03
Experimental assignment: casting their own soft robot and a homemade video on a Discord channel	8:00 - 9:00	daily setup by the educational team					Reflective assignment: write a 2-page report on two reflection questions
	9:00 - 10:00	Welcome and introduction	Progress update	Progress update	Progress update	Final presentation	
	10:00-12:30	group work on '4 essential research questions in soft robotics' (Research groups 1 to 4)					
	12:30-13:30	Lunch break	Lunch break	Lunch break	Lunch break	Expert presentation and group discussion	
	13:30-16:00	setting the 'ROBOGYM challenge'; design concept deadline*	progress update*; Group work on the ROBOGYM challenge (Design teams A to D)	progress update*	'ROBOGYM' demonstration	extra time	
	16:00-18:00	extra time	extra time	extra time	extra time	Goodbye reception	

Figure 2: Planning of learning activities to become an expert in soft robotics in only one week (are potential educational improvements).*

2.4 Course development and learning objectives

During creative ABC sessions (Young and Perović, 2016) and ACAD design (Goodyear et al., 2021) learning objectives were listed and discussed with members of the educational team, including two educational developers and the direct involvement of PhD-students. The ABC framework assumes six active learning activities that describe how students interact with the material and construct their knowledge. Four of these (acquisition, inquiry, practice, production) refer to individual learning, while collaboration and discussion refer to social learning. From the start on, we had the intention to let students primarily build lasting knowledge in a self-paced context by cycles of learning activities, rather than absorbing traditional lectures as a passive student. At the same time, students foster sufficient expertise and self-confidence to engage in lively discussions with experts and thus become acquainted with a vast and growing field of research. As the course has time constraints - the on-campus activities must be organized within a timeframe of 5 days (Figure 2) - four main learning objectives emerged, namely:

A. creation of experimental silicon rubber actuators using simple molds and understanding the fundamentals and pitfalls of this technique;
B. design, create, evaluate and demonstrate a soft robot that can pass several obstacles (including problem definition and specification);
C. master a specific research topic by literature study and peer discussions;
D. a personal (written) reflection on state-of-the-art research and evolution of the scientific field through self-reflection.

3 COURSE OUTLINE

3.1 Pre-course assignment

Approximately two weeks before the start of the ATHENS week (figure 2), students receive a 'Do It Yourself' soft robotics kit, giving them basic materials to create self-made inflatable soft actuators (leaning goal 1 and learning objective A). This DIY kit contains 2-component silicone rubber, a syringe, connection pieces, safety gloves and an instruction flyer. Via this first experimental assignment, the students cast their own soft robot at home and experience first-hand the capabilities and limitations of soft actuation and production. The amount of silicone rubber is intentionally limited to ensure students focused on a well-thought approach instead of playing around. The first assignment for the students is three-fold and students follow the procedure to:

- fabricate a first soft structure by shaping rubber in a generic mold;
- create a soft inflatable actuator that displays an extension deformation when inflated and measure the deformation of the actuator during inflation.
- based on the lessons-learned from their own experiments and from the experience of others, we ask to students to reflect and retry.

Students are thus instructed to pay extra attention to their design flaws they discover or experience, plus post their results on a forum for discussion and reflection with their peers. The students thus initially work independently and capture their achievements on a homemade video, which is subsequently shared with fellow students via a dedicated Discord channel. The use of such a digital platform promotes high-quality active participation and design strategies, which theoretically lead to significant better end grades (e.g., Miller et al., 2018). Students also get to know each other in advance in an interactive way.

3.2 ATHENS week – Research groups and design teams

During the ATHENS week, research groups are formed (groups 1 to 4 in figure 3) and each group has a different research topic to master (supplement 1). Based on a selection of additional trigger questions and tag words, students conduct background research and give a daily update for their peers, plus a final presentation on day 5 for invited soft robotics experts, thereby getting fully prepared for an in-depth discussion with experts and peers. This aligns learning goal 2 with objective C, as students learn to understand the essential problem definitions and solutions offered in the literature that are all connected to the design, fabrication, control and application of soft robots. Students thus elaborate an essential research question over 5 days, supported by additional sub-questions each day and the gradual release of accompanying literature (articles, conference papers, video's, etc.). Students are also required to present their intermediate progress each morning, receiving direct feedback from the mentors (teaching assistants and professor) on how to proceed further while fine-tuning their research question. On day 5, experts join the final presentation and afterwards, show their state-of-the-art research. During these expert presentations, in-depth discussion is stimulated, merging multiple research questions into one comprehensive overview of the main research topics (learning goal 3 and learning objective D).
During the afternoon sessions, learning activities are focused on the actual creation of self-made, functional, inflatable soft robots (learning goal 2 and learning objective B). These design teams (teams 1 to 4 in figure 3) focus on experimental aspects and develop rudimentary soft robots by using everyday components (balloons, tubes, straws, syringes, etc.). During these self-paced design sessions, informal feedback is

given by the mentors if students face design problems. The students need to go in competition with each other and develop an inflatable soft robot that navigates through an obstacle course. However, the main learning activity is to be creative and experiment with the fabrication, actuation, control and navigation (skill development of learning goal 1). Students thus need to assess and define the 'obstacle' problem by adding design specifications or additions to their soft robot. Four adjustable obstacles are given, all connected to different motions and each group can adapt the severeness of the obstacles, to gain more points (see supplement figure 2). As such, success can be expressed by their capability to pass the obstacles. This Robogym challenge is assessed on the fourth day by the expert team, which also serves as a low-threshold personal introduction, asking questions about their design choices and difficulties, and how they implemented their ideas.

3.3 Post-course assignment

The final assignment is a personal reflection to be handed in as a 2-page report dealing with the following questions (learning objective D):

- 'What are the current challenges in soft robotics?'
- 'Can you give a recommendation for future research?'

We ask the student to answer these questions using the knowledge of their own research group and by incorporating the shared information and awareness that gained during the daily updates, discussion and expert presentations (learning goal 3). We also emphasize that, although the assignment is individual, their fellow students are now a source of expertise to discuss future research ideas. The deadline of this assignment is set to be 2 weeks after the final day of the course.

3.4 Student groups and evaluation of learning outcomes

For the research topics, the division into groups is based on their activity on the forum and videos (learning objective A). We tried to go for homogenous groups to ensure a good mix of nationalities and enthusiasm. The design teams, for the afternoon assignment, are created on the spot by a raffle. Therefore, students are continuously switching between groups after the lunch break and consequently strengthening the social cohesion. Students are permanently evaluated based on their design efforts for the Robogym challenges (objective B), their research progress (objective C) and a quotation on their final, individual assignment (objective D).

Additionally, based on a daily questionnaire, the research progress and design challenge is monitored, and at the same time the growth of the corresponding skills is charted to map in an informal way the individual learning outcomes. Here we do not focus on the summative scores of individual students but discuss their personal evolution based on daily self-reflections (Figure 3 and SI 3 & 4). Analog to Forbrig et al. (2022) students are asked to position their skill development (research and design skills) and team progress (research questions and design challenges) on a scale ranging from 0 (a novice with no expertise or no idea how to start) to 10 (feeling like an expert or research question/design challenge finalized). Additionally, their sentiment is tracked by emoticon indicators ranging from 'happy' (counts as +1 point), 'neutral' (0 points) and 'sad' (counts as -1 point), which we use to adapt our daily mentoring. At the end of the week the students are asked how they experienced the educational setup. Also, the mentors (teaching assistants) and experts rate the students' performances in a comparable informal way.

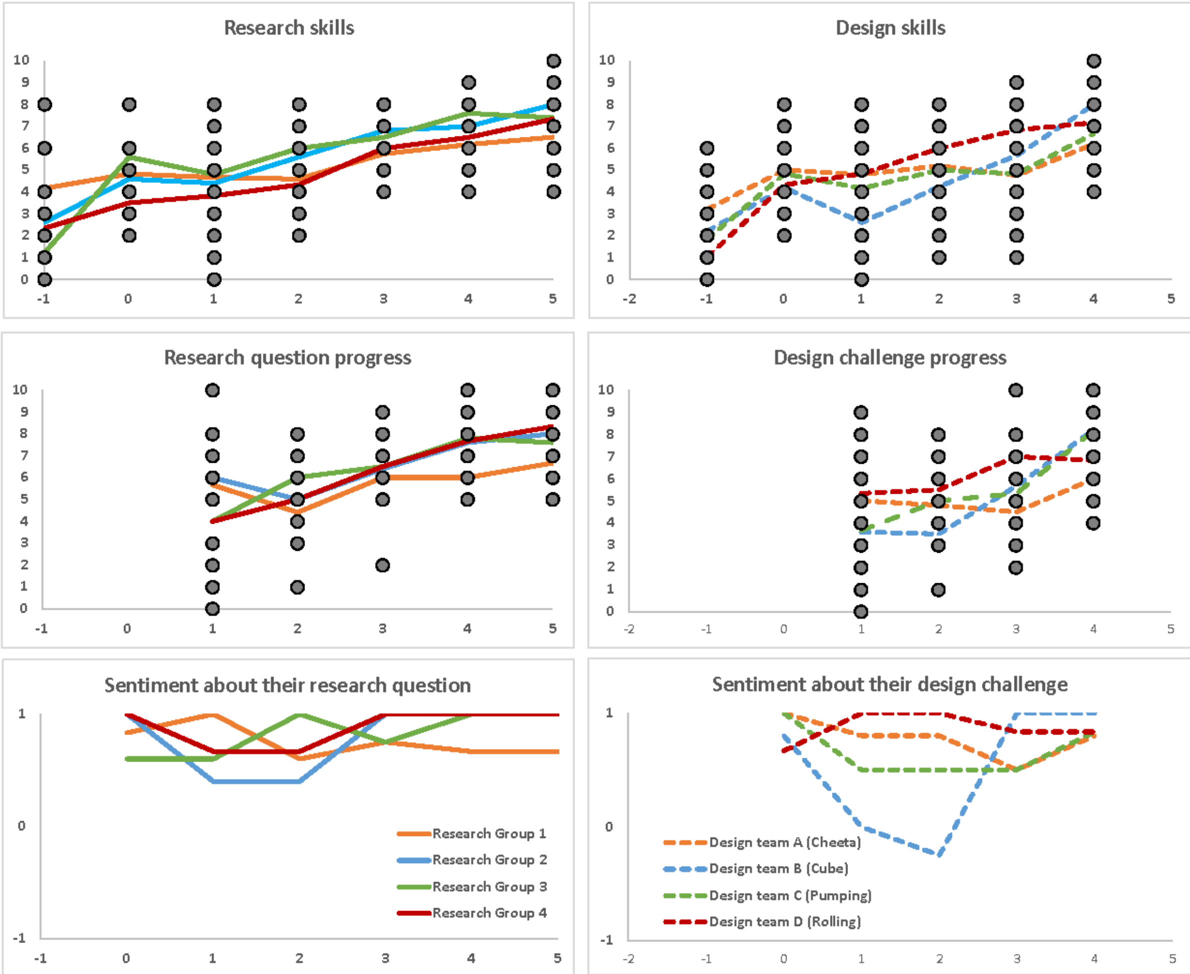

Figure 3: Self-reflection scores of the students, ranging from 0 to 10, are based on daily surveys. Sentiment scores range van +1 ('happy') to -1 ('sad'). Colored lines reflect the averages of the different Research Groups (1 to 4) and Design Teams (A to D). The horizontal axis codes represent the daily evolution (prior to the pre-course assignment and the start of the ATHENS week equals respectively -1 and 0, whereas 1 to 5 represent their self-reflections by the end of each day).

4 RESULTS AND DISCUSSION

4.1 Self-evaluation scores

After each discussion and design moment, we ask students to put themselves on an axis going from novice to expert about soft robotics and we aspire to see their level of expertness increase over time. The graphs indicate that students' skills and progress improve over time (figure 3 and supplementary data 3 and 4). All research groups and design teams have comparable upward trends in their scores and report a daily average increase in skills and progression in their efforts, although not all students indicate that they consider themselves as so-called experts by the end of the week. Confidence levels sometimes dropped within the design teams, related to limited progress that day, but rose even steeper within the following days. Based on the survey data and observations by the outside experts, we achieve our wanted level of expertise without creating the feeling of being lost or overworked. We do acknowledge that during the design phase students express fear of failing, frustration and limited success moments. We also realize that their personal judgements need to be better steered as some students overestimated their expertise levels during the first days. An additional questionary can be added at the start to help students better position themselves. Nevertheless, we hope by improving the skills of participants, and thus increasing their metacognitive competence, we help them to recognize the current limitations of their abilities. In addition, questions about group dynamics and their roles in the group functioning (e.g., leadership, …) could be a valuable addition.

4.2 Lesson learned from the prototype course

We aimed at an initial skill and knowledge development of soft robots by molding silicon rubbers (learning goal 1 and objective A). In our setup, the flipped learning concept by introducing the DIY package is accepted well by the students although experiments are not always successful and students hesitate to share their 'failed' molds on the digital platform, whereas others are proud of their success. This pre-learning outside the classroom paved the way for social interaction during the first day.

- We consider this first-hand experience successful as it acts as an incentive for students to learn, plus continue to learn, and boost their motivation
- As such, the learning outcome of goal 1 is positively evaluated for this part.

Learning activities of goal 2 facilitate on how to design, fabricate and control soft robots (theoretical approach). The theoretical part on day one starts with a general presentation on soft robotics and a critical self-reflection on the DIY molding experiments. The intention is to give a broad overview of the capabilities of soft robotics and their application potential, and ends posing the research questions that are essential in the field and thus the starting point for groupwork (learning objective B). Each group analyzes one of the essential research questions (see SI) and give a daily progress update to the peers. They have approximately 4 times 2.5 hours to do so, which is sufficient. With this we aspire knowledge and insight sharing between groups, helping them to advance during the next days, but also to ensure that they do not lose sight of the bigger picture. During the week, the mentors (professor and teaching assistants) are regularly available to the students, to ask critical questions, help them fathom research papers and instigate internal discussion. They are however not there to give answers and merely guided the students towards online sources (journal publications, conference recordings, research group websites, popular videos, etc.). At the last day, each group gives a final presentation, this time for the experts as well and start their preparation for the personal reflection (objective D).

- We notice that students need more preparation time the first day to understand the basic concepts and hypothesis related to their research question and are hesitant to start the proposed problem- and project-based setup. Even though we want to avoid classical lectures, we realize that a more structured starting point, levelling the understanding of basic concepts is beneficial and enable a better, more equalized, starting point for the research groups.
- Although we stated that the focus of this progress update is not on the form, but on content and concept, we notice that the first presentations (start of day 2) are presented as a literature study instead of a research hypothesis. Instructions were finetuned and during the final presentations, students focus better on the content and hypotheses, and are open for more discussion and opinions.
- We experience that these essential research questions have enough substance to broadly cover the basics of soft robotic technology, while allowing them to explore and understand the literature (objective C) and are capable of discussion

about state-of-the-art research (objective D). These trigger questions (see supplementary data) give them sufficient new insight to identify knowledge voids, that need to be further investigated. Furthermore, these daily triggers match their increasing skill-level throughout the week.

- Based on our experiences and interpretation, no further tweaking is needed for these (sub)questions and only more structure is needed at the start. The learning outcome of goal 2 is thus sufficiently reached as students were able to master a specific soft robot topic (learning objective 2).

For the design challenge in the afternoon (learning goal A, objective B), the learning outcomes were not fully reached. The obstacle run is considered as too difficult to achieve in one week and in fact limits student motivation during the intermediate days (see the drop in sentiment scores in figure 3) as their prototypes were for example not functioning on day two or failed during test runs on day three. A general observation, made by both students and mentors, is that students remain too long in a theoretical phase instead of experimenting with soft robot parts to figure out their preferred deformation of the soft parts (problem specification and implementation).

- Students and mentors report lack of focus and time during the afternoon sessions, thus more guidance and constraints are recommended. Less complicated design challenges are suggested and access to functional prototypes to learn by inverse engineering are an option to speed up the design process.
- Implementation of a deadline for a design concept, a showroom of demo models of actuators and daily progress updates, including a roadmap of intermediate goals and feedback moments, will be explored in the future. This will enable a better focus on controlling the behavior of the soft robot and as such, making more successful attempts during the Robogym demonstration.
- The key here is to fail faster and learn earlier, and by doing so, students will develop the necessary skills and knowledge for better problem definition/specification and thus increase their success rate by overcoming more or all obstacles.

4.3 Feedback from the students and the invited experts

Students particularly appreciate the self-paced learning atmosphere with a focus on growth-mindset, the teamwork experiences within an international network and being able to discuss with several senior experts, which explore frontiers of current knowledge (similar to the results of Forbrig et al., 2022). Many of the students have in-depth and original questions during the presentations at the last day, indicative of mastering the topic and openness for more awareness. The positive feedback from students indicate they learn a lot and gain confidence in their personal development of soft skills such as teamwork through discussion and co-creation, surprisingly also presentation skill improvements are reported as a side-effect. On a need-based perspective, our motivating teaching and learning opportunities, resulted in an autonomy supported learning setup in which students are very participative and mentors offer (meaningful) choices in how students deal with learning opportunities and optimally follow their pace (Alterman et al., 2019). Students like the daily structure and the presentations as intermediate goals, accessibility of the teaching assistants as mentors and the coworking-friendly learning environment in a high-tech collaborative room, which was praised regularly. Experts commented also positively regarding the students' performance, based on the research topic discussions and functionalities of the created soft robots.

5 CONCLUSIONS AND OUTLOOK

Although our setup is still within a development stage, the invited experts express their willingness to apply our educational shift. We expect to further finetune the concept by iteration within the network of soft robotics experts and transfer the setup to other courses. Therefore, we consider this educational approach, originally proposed by Forbrig et al. (2022), as a valid teaching method to achieve top-level effective learning as its generate strong dynamics, without an intensive didactical work load. Based on the positive feedback, our faculty wish to implement it for other ATHENS courses, plus promotion throughout our network to maximize learning experiences of students.

6 SUMMARY AND ACKNOWLEDGMENTS

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SUPPLEMENTARY MATERIAL

Research group 1: How to create an actuator for a specific functionality?

Day 1	Different actuation mechanisms
Day 2	Design spaces and how they lead to different force, stiffness & deformations
Day 3	Multi-modal actuators (stiffening, shape shifting & multi-actuation)
Day 4	Inverse design

Research group 2: How to control a soft robot that is interacting with its environment?

Day 1	Difference between hard and soft robots and implications to control strategies
Day 2	Feedforward control of soft robots
Day 3	Sensing of deformations through soft sensors
Day 4	Feedback/model-based control of soft robots

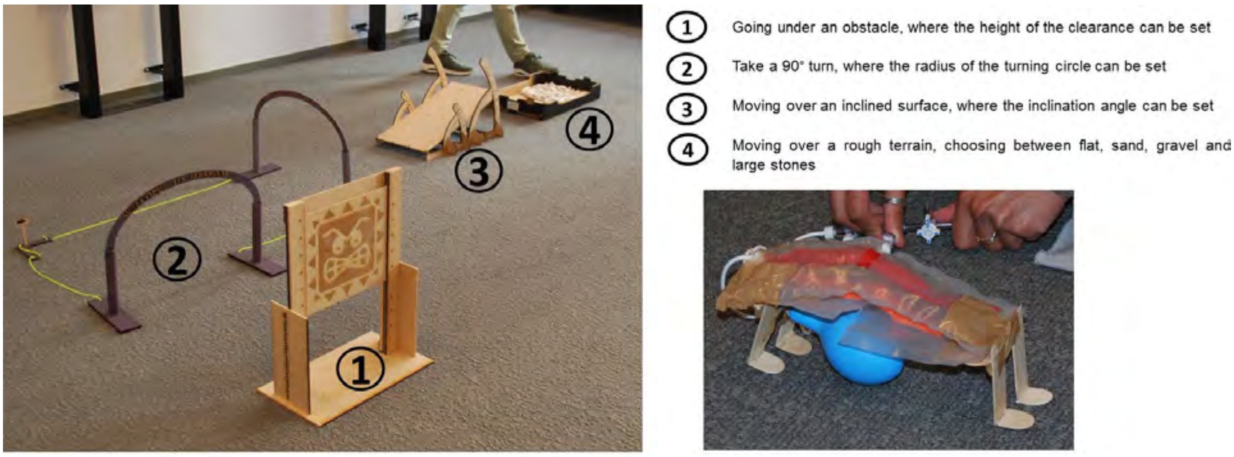
Research group 3: How to make soft robots at different length scales?

Day 1	Fabrication processes at the cm-scale and their limits
Day 2	Towards more complex architectures, by direct defining geometries
Day 3	Very small and very large-scale manufacturing
Day 4	Physics based manufacturing

Research group 4: How to make soft robots untethered?

Day 1	The origin of tethers in soft robots
Day 2	Untethered soft robots by embodying energy
Day 3	Harnessing energy from the environment
Day 4	Embodied Intelligence as a way towards autonomy

Supplement 1: the essential research questions allocated to each research group, including the trigger questions per day.



Supplement 2: setup of the Robogym challenge obstacle run and prototype soft robot

	prior	start	day 1	day 2	day 3	day 4	day 5
number of respondents (N)	22	22	22	19	19	22	22
				Research skills			
Research group 1 (av. score)	4,2	4,8	4,7	4,6	5,8	6,2	6,5
Research group 2 (av. score)	2,6	4,6	4,4	5,6	6,8	7,0	8,0
Research group 3 (av. score)	1,2	5,6	4,8	6,0	6,5	7,6	7,4
Research group 4 (av. score)	2,3	3,5	3,8	4,3	6,0	6,5	7,3
				Research question progress			
Research group 1 (av. score)	/	/	5,7	4,4	6,0	6,0	6,7
Research group 2 (av. score)	/	/	6,0	5,0	6,4	7,6	8,0
Research group 3 (av. score)	/	/	4,0	6,0	6,5	7,8	7,6
Research group 4 (av. score)	/	/	4,0	5,0	6,5	7,7	8,3
				Their 'feeling' about their research question			
'happy' (N)	/	19	15	12	17	20	20
'neutral' (N)	/	3	7	7	2	2	2
'sad' (N)	/	0	0	0	0	0	1
Research group 1 (av. score)	/	0,8	1,0	0,6	0,8	0,7	0,7
Research group 2 (av. score)	/	1,0	0,4	0,4	1,0	1,0	1,0
Research group 3 (av. score)	/	0,6	0,6	1,0	0,8	1,0	1,0
Research group 4 (av. score)	/	1,0	0,7	0,7	1,0	1,0	1,0

Supplement 3: Self-assessment scores of the research skill development and research question progress.

	prior	start	day 1	day 2	day 3	day 4	day 5
number of respondents (N)	22	22	22	19	19	22	/
				Design skills			
Design team A (Cheeta; av. score)	3,2	5,0	4,8	5,2	4,8	6,2	/
Design team B (Cube; av. score)	2,2	4,2	2,6	4,3	5,7	8,0	/
Design team C (Pumping; av. score)	1,8	4,8	4,2	5,0	4,8	6,7	/
Design team D (Rolling; av. score)	1,0	4,3	4,8	6,0	6,8	7,2	/
				Design challenge progress			
Design team A (Cheeta; av. score)	/	/	5,0	4,8	4,5	6,0	/
Design team B (Cube; av. score)	/	/	3,6	3,5	5,7	8,2	/
Design team C (Pumping; av. score)	/	/	3,7	5,0	5,3	8,2	/
Design team D (Rolling; av. score)	/	/	5,3	5,5	7,0	6,8	/
				Their 'feeling' about their design challenges			
'happy' (N)	/	19	16	13	14	19	/
'neutral' (N)	/	3	4	3	4	3	/
'sad' (N)	/	0	1	3	1	0	/
Design team A (Cheeta; av. score)	/	1,0	0,8	0,8	0,5	0,8	/
Design team B (Cube; av. score)	/	0,8	0,0	-0,3	1,0	1,0	/
Design team C (Pumping; av. score)	/	1,0	0,5	0,5	0,5	0,8	/
Design team D (Rolling; av. score)	/	0,7	1,0	1,0	0,8	0,8	/

Supplement 4: Self-assessment scores of the design skill development and design challenge progress.

ENABLING STUDENTS TO EVIDENCE AND ARTICULATE UNESCO FUTURE COMPETENCIES IN STUDENTS THROUGH RESEARCH-BASED EDUCATION FOR SUSTAINABLE DEVELOPMENT

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Conference Key Areas: *Engineering Skills and Competences, Lifelong Learning for a more sustainable world; Addressing the challenges of Climate Change and Sustainability*

Keywords: *Education for Sustainable Development, Competencies*

ABSTRACT

Today's complex global challenges call upon a different pedagogical approach to Higher Education (HE) that is fit for the purpose of preparing our students – to paraphrase the words of Sir Jonathan Porritt - not only for the world of work, but the work of the world. Indeed, we can and should be preparing students for both, as it is through their professional lives and activities that they will arguably be able to have the most positive impact on these global challenges. Consequently, re-focusing teaching on ways of thinking, being and practicing, the so-called 'head, heart and hands' framework, should be done in a way that actively stretches students beyond the comfort of their disciplinary boundaries, knowledge and skill sets.

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This paper will present the University of Strathclyde's practice and experience of establishing their award winning Vertically Integrated Projects for Sustainable Development (VIP4SD) programme, as an exemplar of how to embed Research-Based Education for Sustainable Development in undergraduate curricula.

This paper will show how VIP4SD provides students with the time and space in their curriculum to develop demonstrable levels of domain expertise and exercise key UNESCO sustainability (and ergo employability) competences. We then discuss how we have sought to evidence this by supporting students to recognise and articulate their competency development, achieved through the experiential and transformational learning provided by the VIP4SD programme.

1 INTRODUCTION

UNESCO define Education for Sustainable Development (ESD) as "the process of equipping students with the knowledge and understanding, competencies, skills and attributes needed to work and live in a way that safeguards environmental, social and economic wellbeing, both in the present and for future generations." (UNESCO 2020). Thew and COP26 Universities Network (2021) suggest that ESD and Climate Education "seeks to equip learners with the transferable skills they need to respond to a wide variety of complex, dynamic challenges including but not limited to the climate crisis". Therefore, ESD is increasingly being viewed and implemented across HE as a pedagogy rooted in active, problem- and inquiry-based, experiential learning that has competency development at its heart. This can lead to transformational impacts on learners and the stakeholders, communities, and organisations that learners interact with, and deliver impact for, during their learner journey.

It is not the purpose of this paper to make the case for ESD, as changes in the sector (and society more generally) make clear the increased demand for it. Most notably, the current QAA guidelines for review of degree Subject Benchmark Statements now explicitly calls for ESD to be embedded at degree programme level across all disciplines (QAA and AdvanceHE 2020). The Engineering Council's most recently published AHEP 4 (Engineering Council 2020) asks for programme learning outcomes to have "a sharper focus on inclusive design and innovation, and the coverage of areas such as sustainability and ethics", encouraging HEIs to "make use of the United Nations Sustainable Development Goals, and Engineering Council Guidance on Sustainability in programme design and delivery." Student-centric drivers such as the SOS-UK Responsible Futures accreditation programme (SOS-UK 2021), which is gaining membership and momentum, is another 'external' force advocating for the mainstreaming of ESD in HE.

1 BACKGROUND

1.1 Vertically Integrated Projects – Embedding Undergraduate Research in the Strathclyde Curriculum

Vertically Integrated Projects (VIP) are a unique approach to undergraduate research-based learning that has been implemented in various universities worldwide (SOS-UK 2021). Georgia Institute of Technology and the University of Strathclyde have been at the forefront of VIP implementation. The VIP programme involves undergraduate and graduate students working together in teams to solve real-world problems proposed by academic leads, industry partners, research centres, third sector organisations, or students themselves. The VIP model is unique because it spans multiple years of study (vertical integration), allowing students, in some cases from across disciplines (horizontal integration, enabling interdisciplinary working) to build upon the work of previous teams and set the objective of future teams. The Strathclyde VIP programme was initiated in 2011, while the Georgia Tech VIP programme began in 1998. Both universities have reported success in improving student engagement, retention rates, and career readiness (Baxter et al. 2011) while delivering real impact to organisations and communities (Marshall et al. 2014) (Cullers et al. 2018).

1.2 Embedding Research-Based Education for Sustainable Development in the Strathclyde Curriculum through VIP

In 2016 University of Strathclyde introduced the idea of aligning VIP with the 17 UN Sustainable Development Goals ("THE 17 GOALS | Sustainable Development," n.d.) to create the Vertically Integrated Projects for Sustainable Development (VIP4SD) programme (Strachan et al. 2019) (Strachan, Logan, and Marshall 2022). The range of existing Strathclyde projects is available on our website ("Vertically Integrated Projects for Sustainable Development | University of Strathclyde," n.d.).

(Kolmos et al. 2016) speak of education *about* sustainability as an assimilation strategy where sustainability *subjects* are included in the formal curriculum,. They contrast this with education *for* sustainability, which involves some modification of the programme and which is an *integration* strategy, going further than the add-on strategy by mapping and coordinating various courses and integrating professional and soft skills. This requires curriculum overview and therefore the support of the academic managers, e.g. program leaders, Deans and Heads of School. The VIP4SD programme follows this integration approach, as it requires coordination and collaboration across and between faculties and programmes as it seeks to embed active learning and skills and competency development in programmes.

While we have anecdotal evidence of students developing a range of skills through their VIP4SD experience, we have more recently sought to find a mechanism of formally measuring and evidencing this. This allows us to not only measure student development in this area (and build their capacity to reflect on this themselves), but also test the efficacy of the VIP4SD programme. To achieve this we have partnered with the developers of an experiential learning platform known as Practera (Practera 2023) to develop a pilot programme, which is explained in more detail later in the paper.

1.3 ESD and UNESCO Sustainability Competencies

A broad consensus is growing between scholars and educators in ESD circles that central to transformational learning experiences are the cognitive, affective and pchyco-motor domains and the interplay between these elements. Core to these domains are the 8 UNESCO Sustainability Competencies, which consist of systems thinking, future thinking, critical thinking, strategic competency, collaboration competency, integrated problem solving, self-awareness, and normative competency. These competencies are categorised as ways of thinking, ways of being and ways of practicing (aligned with the head, heart and hands framework) by QAA/Advance in their UK HE Guidance for Embedding ESD, and are identified as crucial in aiding students to foster their knowledge, understanding, values, attitudes and behaviours in order to make a meaningful contribution to sustainable development (QAA and AdvanceHE 2020). Neither the UK HE ESD Guidance nor ESD for 2030 UNESCO framework (UNESCO 2020) are prescriptive about how the competencies are delivered or developed, but instead aim to facilitate institutions to create curriculum architectures and subject relevant content and embrace suitable pedagogies which support and enact these competencies for sustainable development. How, then, can ESD be implemented holistically through a systemic, whole institution approach?

1.4 Pedagogies for ESD

The pedagogical pillar is key to integrating ESD into curricula and for effective operationalisation of key competencies to occur. It requires transformative, critical and emancipatory pedagogies (Sandri 2020) underpinned by concepts and values that empower students to critically explore beliefs, knowledge and values, and develop a sense of critical consciousness and agency (Ukpokodu 2009). (Brundiers and Wiek 2017) call for pedagogical innovations that are integrated, holistic, that provide real-world, experiential, transformative, context-specific learning experiences as sustainability cannot be learned independent of context (Sterling 2004). This also calls for real-world learning opportunities that take students beyond a theoretical understanding of ESD and encourage the development of practical competencies. Learning experiences should be holistic, integrated and experiential and unify the cognitive, affective and psycho-motor domains (Bonello and Musumeci 2022). Deep learning for sustainability requires learners not to be taught what to think but to develop the necessary dispositions to act successfully in different contexts autonomously and should be seen as a learning process not the ‘rolling out’ of predetermined behaviors and predefined outcomes (Vare and Scott 2007).

1.5 Enabling students to articulate competency development through VIP for Sustainable Development

The VIP4SD model presents a new way of teaching and learning for both students and staff. As such, it presents new ways of assessing students as well, ways that recognise and reward students not only for their disciplinary learning, but for their skills and competency development. However, how we might achieve this is less clear. As Strathclyde’s VIP4SD team sought to more fully embed ESD and sustainability competencies in the programme, we were also faced with the challenge of how to do this meaningfully and in a way that did not present competency development as an “add-on” to students’ project work. Rather, we were faced with the challenge of integrating competency development within the core learning experience, and enabling students to see the value of being able to recognise and articulate their competencies in relation to their role as global citizens, as well as their professional development and employability prospects. Furthermore, the VIP4SD model is intended to allow students to spend more time working on a dedicated area of sustainability-related research, and so offers a greater opportunity for students to develop and hone these competencies over a longer period of active participation.

Practera, an ed-tech provider that supports experiential learning via its online platform, presented a way of managing VIP4SD projects by more directly connecting students and academic leads for project supervision, progress reporting and feedback purposes. It also supported consistent competency reflection and peer feedback. We entered into a pilot with Practera in academic year 2021/22 to work with us to develop a student competency reflection and articulation platform and are currently finishing up our second year of collaborating with them. What follows describes the platform design process, its features ,and how these have supported the students in identifying and articulating their competency development. Later we discuss the data captured and what we have learned about the programme.

2 METHODOLOGY

2.1 Co-designing a platform to support experiential learning and students' competency reflection and articulation

While we understood anecdotally that students were gaining and developing skills and competencies through their VIP4SD experience, we had no mechanism of proving this qualitatively or quantitatively. Practrea presented a ready-made solution to this challenge; as we are a small team with limited resources and with limited expertise in digital learning, this was an attractive option. This gamified platform was also accessible and engaging for students, academics and the programme co-ordinator.

The workflow design requires students to fill in a team log every other week and submit a competency reflection in the weeks in between. This reflection requires students to articulate which of the 8 UNESCO competencies they have exercised and developed most in the previous couple of weeks, focusing on up to 3 competencies.

At the end of each semester students engage in a 'Team 360' peer review, which involves leaving anonymised feedback to each other. In turn, students receive their own feedback from peers and are asked to reflect on this feedback in the 'Post Team-360 Reflection'. This presented an opportunity we had not yet been able to provide through VIP4SD. At the end of the academic year students then use the feedback and their own reflections throughout the two semesters to map their competency development across the programme and populate their Competency ePortfolio, which can then be made available to link to their CVs and LinkedIn pages.

The platform's focus on feedback loops – whereby students submit work, reflections and team logs and academic leads provide short pieces of regular feedback - encourages and enables consistent academic support that incentivises and bolsters student engagement. In summary, the benefits of developing this platform included 1) offering the opportunity for students to reflect, understand, and – crucially – articulate their competency development in real time as they progressed through their project; 2) enabling and streamlining consistent academic and peer feedback; 3) providing the VIP4SD team with data that evidenced the programme's efficacy in developing the sustainability and employability competencies that employers are increasingly searching for, and which are so key to effectively embedding ESD.

The initial work of this pilot involved designing and configuring the platform to fit with VIP4SD workflow and structure, which takes place over 22 weeks from October to December and January to April (the autumn and spring semesters). The initial design was completed by the Practera team, following a brief from the VIP4SD programme team. In year two, the programme design remained largely the same, and so could be modified slightly by our Programme Co-ordinator. The platform presented a project workflow divided into 'milestones' that aligned with the VIP4SD programme's key submissions and assessments. These included a statement of intent at the beginning of semester one – where the group outline their aims for the project over the course of the academic year; a group literature review presentation at the end of the first semester, which is designed to demonstrate the students' understanding of the project's central problem, the state-of-the-art and how their research area engages with and impacts the SDGs; a team poster to be presented at a University-wide ESD@Strath student conference, held at the end of the second semester; and a final group report and reflection. Additionally, students must compile and submit their Competency ePortfolio as an assessed element. This draws on the competency reflection logs (mentioned previously) that they are routinely prompted to maintain throughout the year via the platform. The students are required to articulate how, when and where they have exercised these UNESCO competencies using the STAR (Situation, Task, Action, Result) framework, to offer a consistent approach to articulating their competencies development. They are also required to append an artifact (a file, report, paper, poster, notes, drawing, code, etc.), which is the output from the task where they exercised a specific competency.

Alongside these key elements are onboarding material, as well as supportive elements throughout. These include, for example, short sections that explain how to produce an effective STAR statement, as well as guidance on the UNESCO ESD competency framework. These elements are an essential aspect of the platform in that they provide scaffolding and motivation for the students in the completion of their competency reflections, which is often the first time the students will have been asked to consider these as part of their educational journey. In the next version of the platform the Competency ePortfolio will be replaced with a customisable tool that enables programme designers to assign an Open Badge for each competency a learner meets the criteria for.

3 RESULTS

The first year of the pilot engaged a sample of 8 teams from a total of 24 VIP for Sustainable Development teams in total, representing 30 students (i.e. a section from the 120 strong programme cohort), and 8 members of staff. The second year saw 7 teams comprising 30 students and 6 staff take part In general, most students reported an increase in their competencies in the final reflection at the end of the academic year. In the baseline competency self-assessment for the pilot year (2021-22), students were asked if they were able to consider the relative costs and benefits of a potential action in order to choose the most important one, the answer to which would indicate their level of competency in systems thinking. This approach – which uses the UNESCO definition of systems thinking - was chosen rather than simply asking students to rate their systems thinking competency as its unlikely that all students would know what systems thinking was. In this survey – which students completed at the beginning of the first semester as part of their Practera onboarding – most students selected 'Very skilled' (40.6%) or 'Somewhat skilled' (again, 40.6%) in response to this statement. In the exit survey at the end of the second semester, the majority more confidently selected 'Extremely skilled' (38.9%) and 'Very skilled' (44.4%). Similar results are seen in the second year (2022-23). When asked in the baseline competency self-assessment if they were able to ‘create their own vision of the future … to contribute to a more sustainable world’ - therefore demonstrating Future Thinking – the majority said they were ‘Somewhat skilled’ (48%) and ‘Not very skilled’ (13%). In the final competency self-assessment, the majority said they were ‘Very skilled’ (48%) and ‘Extremely skilled’ (28%), with the remaining students selecting ‘Somewhat skilled’ (24%) and no one reporting no level of skill.

While these results demonstrate the efficacy of the programme somewhat (as these are self-assessments of students’ own skill level) we also recognised some need for improvement in various aspects of the programme in both years. For example, while the platform built in supportive sections that explained the competencies, we realised that more than this was needed to get students to not only understand what the competencies were, but to value their development of them and understand why it was important for them to be able to articulate them. Initially, students were being asked to reflect on skills in their biweekly group logs; for example, they were asked to describe (as a group) what they had worked on that week and discuss any challenges faced, and to then reflect on their competency development with this in mind. We decided in year two to separate these exercises into biweekly group updates and biweekly individual reflections, due in alternate weeks. The individual reflection made more sense in that it followed the same format as the Competency ePortfolio the students would complete at the end of semester 2, which is also an individual submission. Submitting these reflections individually may have also led to more frank and representative responses. We also made the decision in the second year of the pilot to rename the competencies, while continuing to use the UNESCO ESD competency framework. This is because it was clear that students did not intuitively connect with some competencies, which perhaps led to them shying away from engaging with less intuitive or familiar ones. For example, students found Collaboration and Critical Thinking easy to recognise and engage with, but seemed to find it more difficult to grasp Normative Competency and Anticipatory Thinking. To aid this, we changed Normative Competency to ‘Values Thinking’ and Anticipatory Thinking to ‘Future Thinking’, while retaining (slightly simplified) UNESCO definitions. Student feedback gathered in anonymised surveys has been largely positive. One student from the 2022-23 academic year noted in free text comments that “referring back to the key skills and competencies throughout the project in the form of reviews captures well how much progress has been made”, while another stated that the project “has offered a platform where I can constantly self-reflect and improve”. However, some students did not see the full benefits of the platform, with one commenting that there were “a few too many deliverables for teams that are engaging with supervisor”, perhaps meaning that the unassessed elements (such as the biweekly reflections) were seen as unnecessary or onerous. Nonetheless, 82% of students Strongly Agreed with the statement “I am likely to use this experience as evidence of my skills in my applications for future opportunities” in the same survey.

While it is to be expected that not everyone will see the value of engaging in competency development and articulation in this way, the challenge for the VIP4SD team going forward is to put more resource into supporting students with their reflections and professional development, and helping them to see more clearly the benefits of this work.

4 CONCLUSIONS AND FUTURE WORK

What has become clear in the two academic years of this pilot is that while the platform provides the tools students need to track, understand, evidence and articulate their competency development, more work is required offline to encourage students to understand why these competencies are valuable *to them* (in becoming more sustainable and globally-minded citizens), their *prospective employers*, and *society* as a whole. Central to this is their appreciation of how their capacity to effectively recognise how, when and where they are exercising and developing these competencies and their ability to articulate them effectively, and how this will increase their employability prospects when sustainability-literate graduates are increasingly being sought after by organisations in all sectors.. To aid this, our aim for the next academic year will be to link up with our Careers and Employability Service and Strathclyde Inspire (the university's entrepreneurship initiative led by our Business School) to develop a more cohesive narrative around competency development, sustainability, employability, innovation and entrepreneurship.

We also hope to have visits from employers in related industries to show students that employers are interested in the programme and the work students are producing, and importantly how and why they value these competencies. A Sustainability Skills Passport is also being piloted at the institution, and we hope that we can encourage students to engage with this initiative and related resources that highlight the value of these wide-ranging skills. We also seek to offer opportunities to link the awarded competency badges with their passport points.

We also plan to more rigorously test the claim that the VIP4SD programme is an effective experiential learning programme that develops student competencies and skills by developing a survey that introduces two control groups to compare VIP4SD students engaging with the Competency Badges. We will use these surveys to compare their perspectives on their competency development with other VIP4SD students (not engaged with the competency reflection and badges), and non-VIP4SD students. However, care and consideration will be required here to avoid bias arising from the existence or absence of a priori and posteriori knowledge of these competencies between the different control groups.

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AUTOMATICALLY SCORED, MULTIPLE -ATTEMPT, RECURRING WEEKLY EXAMS IN A PHYSICS COURSE: CAN THEY IMPROVE STUDENT WELLBEING AND LEARNING OUTCOMES?

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ABSTRACT

This paper describes the arrangements and assessment methods employed in the engineering physics online courses offered by Tampere University of Applied Sciences. The grading process involves the use of automatically assessed weekly online exams in Moodle, which comprise mostly numerical questions, as well as conceptual questions, force diagrams, and multiple-choice questions. Students are allowed to attempt each exam three times, and their best score is recorded. The questions and initial values were randomized for each try to reduce possibilities for trial-and-error method and copying from peers. By completing the week exams with enough points, the students were able to pass the course with low grades. The main idea was to make the course completion more flexible and time and place independent and reduce exam stress. It also reduced teachers' workload in relation to assessment and retakes. Most students took more than one attempt in the exams, and the majority of students who initially scored low points showed improvement in subsequent attempts. According to student feedback vast majority of students agreed that this exam arrangement worked well and that retakes reduced stress, was flexible and improve their learning experience and outcomes. Almost no one would like to change back to one-attempt exam checked by the instructor.

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1 INTRODUCTION

The assessment methods are chosen to align with the curriculum and the intended learning outcomes of a course. In engineering physics at the bachelor's level, the topics, and problems to be solved require both conceptual understanding and algebra/calculus-based problem-solving. Some typical elements used in the assessment are formative assessments during the course with the help of quizzes, forms, or polling surveys, laboratory, and project work with written or oral reports, homework assignments, and summative assessments containing mid-term exams and/or final exams. However, this study concentrates only on automatically scored, recurring, online weekly exams.

Taking an exam typically has two opposing effects on students' behaviour: the exam situation is often perceived as stressful, but on the other hand, students' effort and intensity of working are at a high level. For example, the review by Richardson et al. (2012) suggests that stress and anxiety are important factors to consider in understanding student academic performance, including performance on exams. The levels of stress and anxiety are negatively associated with academic performance, including exam scores. Also, the study by Pascoe et al. (2020) highlights the negative impact of stress on academic outcomes, including grades, attendance, and scores. Students who experience high levels of stress are more likely to drop out of school or fail courses. Stress levels typically increase during mid-term and final exams (Zunhammer 2013).

The question arises: how to reduce the stress level but keep the working intensity high? How to better harness the exams to work as a learning tool rather than only a grading tool without increasing the instructor's workload too much? According to our previous study (Suhonen & Tiili 2021), the students spent a considerably long time in interaction with an automatically scored exam if they were allowed to. In that study, the students could retake an automatically scored "basic level exam" as many times as they liked or needed to pass the course. The total time they spent was many times higher than they traditionally do in paper exams. This finding encouraged us to further increase the weight of automated, recurring exams in the course. So, the solution to the question stated was, in our case, to use automatically scored, recurring, week exams that the students were able to take three times and increase their weight in the grading of the course. The exam arrangements are described in more detail in the next chapter.

Automatic assessment provides students with immediate feedback on their performance, allowing them to identify their strengths and weaknesses and adjust their learning strategies accordingly. It also provides consistent grading, reducing the possibility of subjective bias or grading errors that can occur when grading manually. Studies have found that students generally have positive attitudes towards automated assessment. For example, according to a study by Ardid and Vidaurre, student comments were generally positive, especially on ease-of-use and its usefulness during the learning process to diagnose the level achieved. On the other hand, there were also some criticisms, especially in terms of clarity of the questions and the rigidity of the automatic scoring (Ardid and Vidaurre, 2018). Overall, automatic scoring of exam answers can improve efficiency, consistency, and fairness in grading, while providing immediate feedback to students and saving instructor’s time.

2 METHODOLOGY

2.1 Engineering physics course - mechanics

The recurring, automated weekly exams were piloted on a bachelor’s level elementary engineering mechanics online course that was offered nation-wide. The platform was Moodle, and the setup was asynchronous implementation with weekly deadlines for exams and one final deadline for measurement assignments and final exam. In the beginning, the course had 167 active participants of which roughly half were students in Tampere University of Applied sciences, the rest were students in other universities of applied sciences in Finland. The course lasted for 10 weeks, and it had 6 weekly (or topic) exams which formed 60% of the course’s final grade. The rest of the points came from either from final exam or from measurement assignments. Measurement assignments are one-topic, relatively simple tasks, which doesn’t need very complicated equipment. In online courses, the equipment has to be easily available at home. Measurement assignments are described in more detail in our previous study (Suhonen 2021). With the week exams alone, it was possible to pass the course with two lowest grades (1-2). The maximum grade is 5. If the students aimed at better grades than 1-2, they needed also take the final exam or measurement assignments according to their own choice.

2.2 Weekly exams

On this piloted course, students had three attempts for each weekly exam and could use all materials during the online exams. Each attempt lasted a maximum of 2 hours, and students were able to retake the exam immediately, although they were encouraged to study between attempts. Each weekly exam had a deadline after which it was closed, and students were provided with a video to explain the solution to the problems. With these arrangements, we have been able to create an environment in which students view exams as an opportunity to learn and grow, rather than simply as a test of their level of knowledge. Additionally, the independence of time and place, together with multiple attempts, reduces the stress and anxiety that the examination situation could otherwise induce.

The weekly exams mainly consisted of the following types of questions: 1) multiple-choice questions requiring conceptual thinking, such as force diagrams; 2) problems based on diagrams, graphs, and measurement data; and 3) problems requiring mathematical solutions. The randomization of initial values was accomplished by using STACK exercises in Moodle. In all cases, there were multiple versions of the same type of question and/or the initial values for the problem were randomized. In this way, we tried to eliminate the possibility of the trial-and-error method in the exam, as well as reduce the feasibility of copying from peers. It was likely that the students had different versions of the questions each time they attempted.

One example of the questions is shown in the figure 1. It shows the question translated into English (A), the question as the students saw it (B) and part of the 12 different versions of the graph for the same question (C). Even though the question was the same in all attempts in this case, the graph changed.

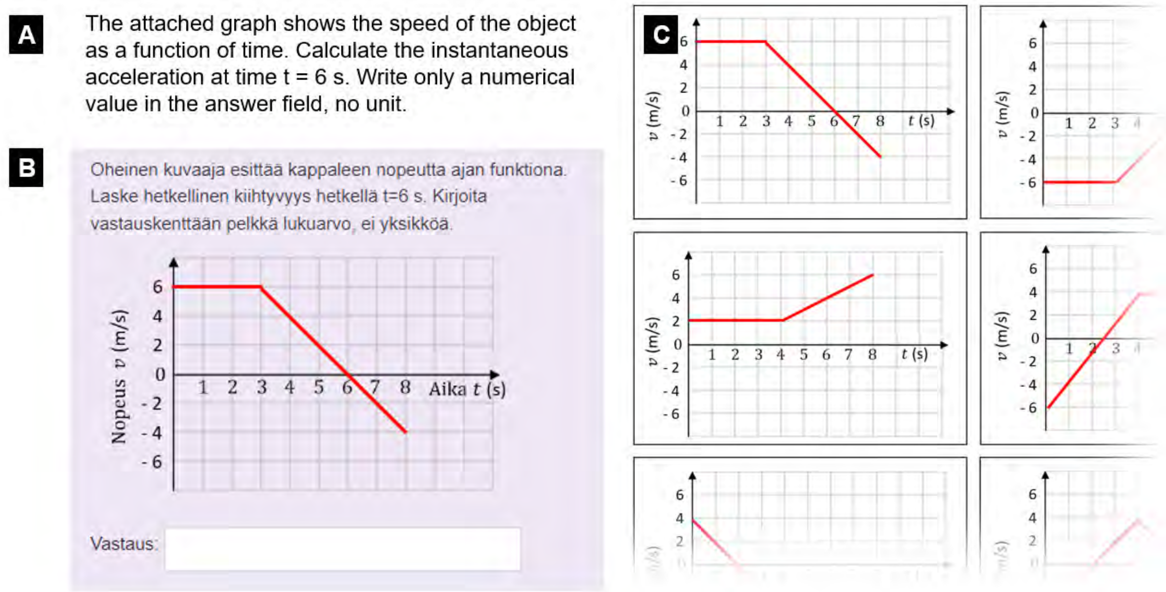

Fig. 1. Example of a week exam problem. A) The question translated into English. B) The question as the students see it. C) Part of the 12 different versions of the graph for the same question.

Another example of a week exam problem is shown in Fig. 2. This question had five similar, but slightly different set-ups (shown in B and C) of the problem. Here also the initial values are randomized (shown with red boxes in B).

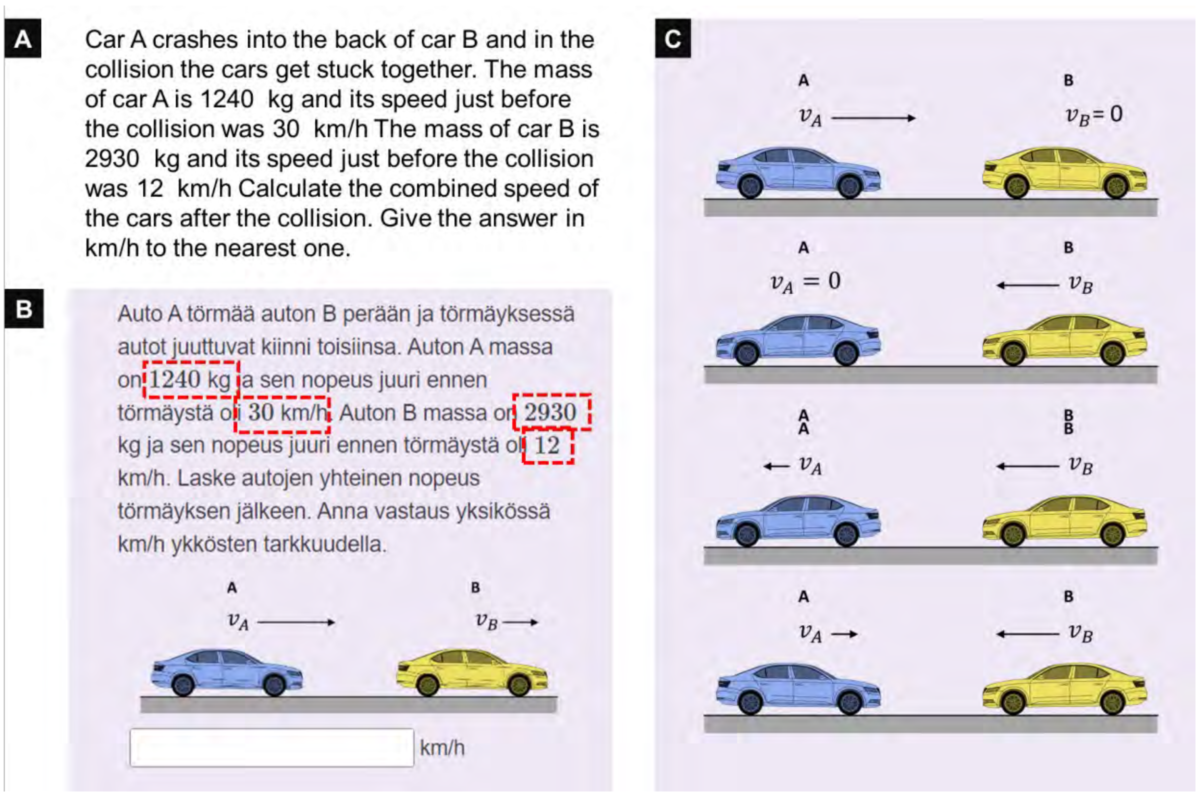

Fig. 2. Another example of a week exam problem. A) The question translated into English. B) The question as the students see it (excluding the red boxes). The randomized values are here indicated with the red boxes. C) Four other versions of the problem set-up.

The maximum number of points for each week exam was 6 and it was earned by solving 3-6 problems (depending on the exam). The scoring was automatic, which is easily done in multiple choice questions but a bit more laborious in other types. In mathematical solutions, the typical erroneous answers were fed to the answer tree in STACK-exercises in Moodle to yield partial points for partially correct solutions. This of course requires that the instructor knows the typical errors in advance. It is also possible to adjust the automatic scoring system after having a look at the student answers. To prevent losing all points for some typing or other small error, the student were asked to check their own answers after publishing the solution video for each weekly exam. If the students felt that they had lost points unfairly, they could ask the instructor for manual scoring.

3 RESULTS

3.1 Week exam results

There were 6 weekly (or topic) exams during the course. The last weekly exam was still open during writing this paper, and it is thus omitted in the analysis. Regarding the first five weekly exams, the number of students, average times and average points for each attempt are show in the table 1 and in the figure 3. The exams yielded similar data and the trends are roughly similar in each exam. The data shows that the majority of the students retook the exam at least once and more than one third on average used all attempts. In all exams, there are slight increases in the average points according to the number of attempts. The average time spend in interaction with one exam goes down from roughly 40 mins of the first attempt to a bit less than 30 mins of the third attempt. There is naturally variation in the times, since the topics and questions are different for each week. Altogether this means that on average, a student has spent 81 mins in one week exam, taken 2.1 attempts and spent 7.6 hours doing all the week exams. This is a remarkable time spent on high-intensity working on an exam situation.

Table 1. Attempts, durations and points for first five weekly exams. The maximum number of points for each week exam was 6 and the maximum time for each attempt 120 min.

Exam attempt	Number of students	Average Time (min)	Average points
1.1	167	53	2.64
1.2	119	38	2.76
1.3	81	34	3.27
2.1	166	41	2.82
2.2	120	32	2.87
2.3	86	27	3.13
3.1	159	41	2.84
3.2	94	29	3.06
3.3	55	26	3.42
4.1	155	40	2.62
4.2	117	24	2.56
4.3	79	18	3.02
5.1	149	33	2.19
5.2	117	28	2.16
5.3	81	27	2.87

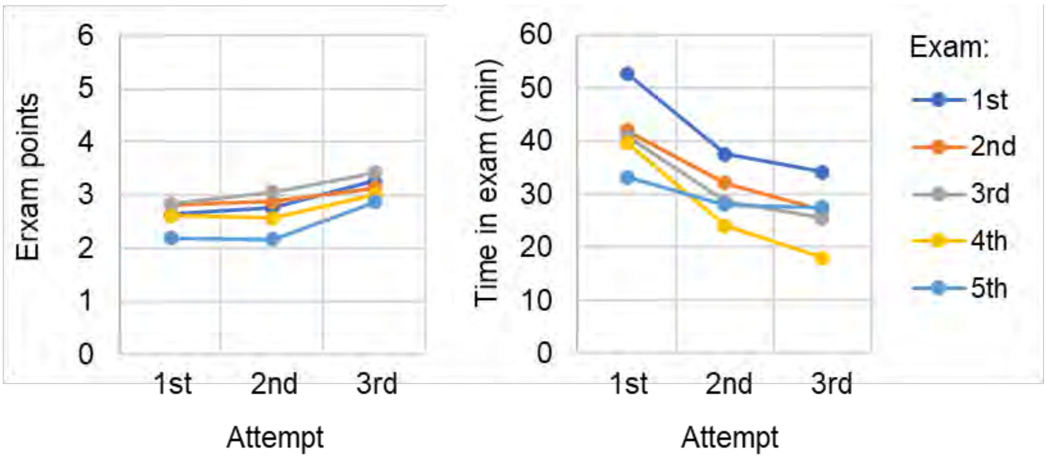

Fig. 3. Exam points (left) and spent time (right) as a function of attempt for the first five weekly exams.

The first exam is investigated a bit more deeply here, and the results are presented in the figures 4 and 5. The point distributions of the first week exam are shown in the Figure 4. It shows the ovarell effect of retakes on the points.The final point distribution is clearly higher than that of the first attempt.

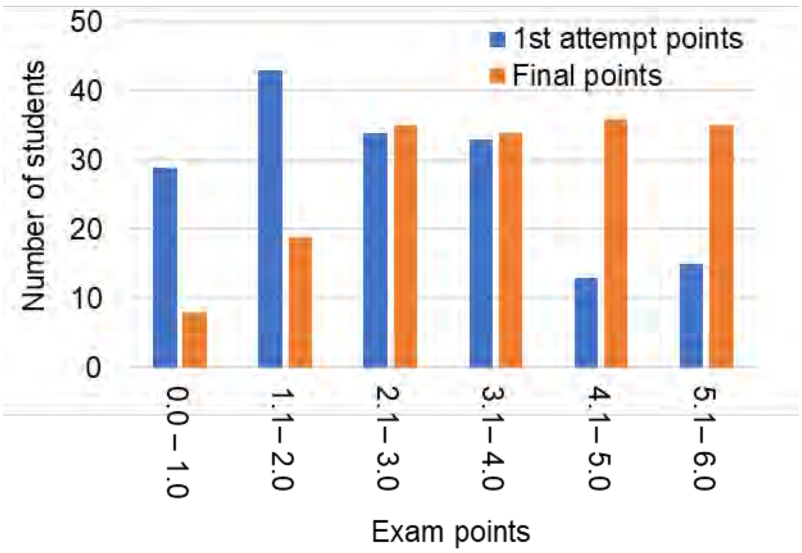

Fig. 4. The points distribution after 1st attempt, and the final points distribution in the first weekly exam.

Fig.5. shows student points and exam time categorized according to the success at the first attempt. The graph data contains only those 81 students who took all three attempts in first weekly exam. We can see that those students who got the lowest points (0-2) at first attempt had a highest increase in their points with successive attempts. Those who scored averagely (2-4) or highly (4-6) at their first attempt actually did worse at the second attempt. This suggests that they didn’t fully realize their need to study in between the attempts and maybe they just had an other try. Anyhow, students used their last attempt more wisely (on average) and got higher points at the last try than with the second try. Those who scored lowest in the first

attempt, used more time in the second and third attempt than those who scored averagely or highly.

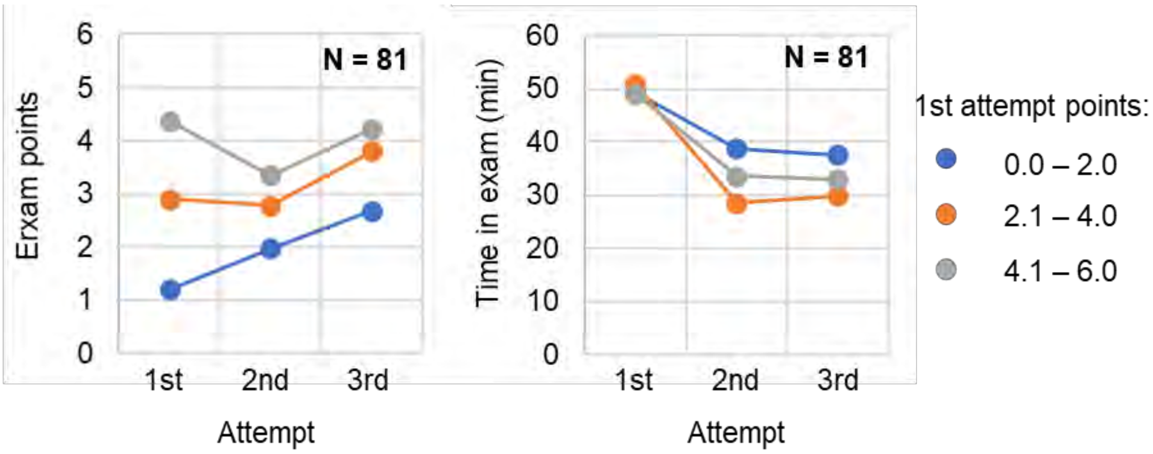

Fig. 5. Exam points (left) and spent time (right) as a function of attempt for the first week exam. The data is categorized according to the success at first attempt.

3.2 Student feedback

The student experiences of this recurring, automatically scored, weekly exams were surveyed using a short online questionnaire. There were 71 answers (43 %) and of them 70 reported that they had used more than one attempt in the weekly exams. This means that more than half of those students who have used many attempts in the exams have answered (see Table 1). Even though the answer percentage was not very high, the responses given truly represent student experiences with the many-attempt weekly exam. The survey contained multiple choice statements on 5-point Likert scale and open-ended questions. The summary of student answers to different statements are presented in the figure 6.

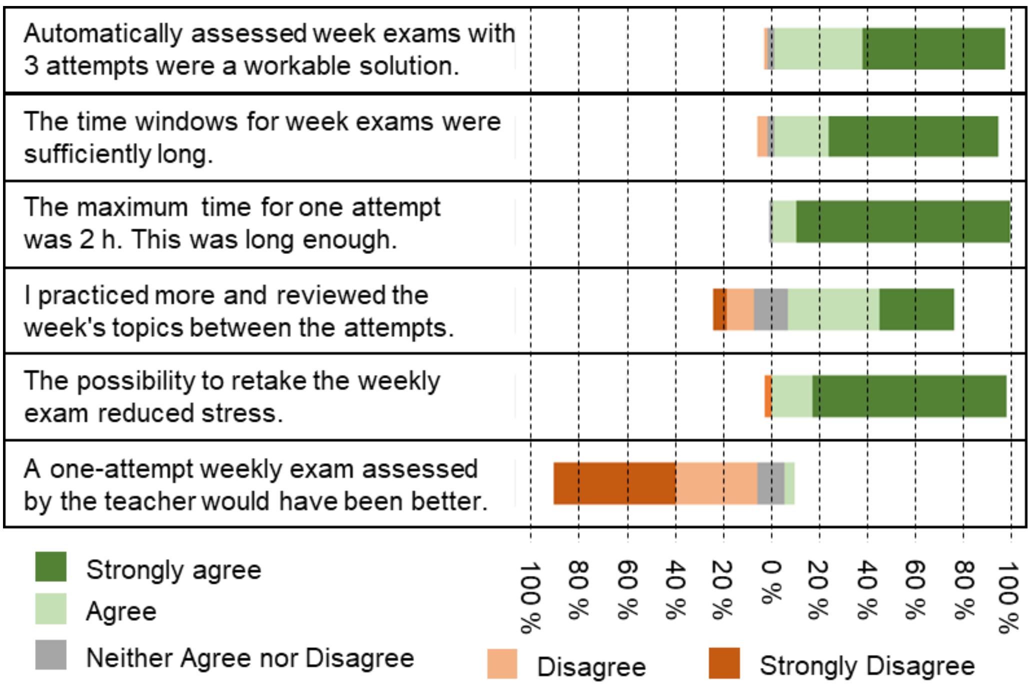

Fig. 6. The summary of student answers to different statements.

Fig. 6 shows the answer percentages to each statement from “strongly disagree” to “strongly agree”. The students found this kind of exam arrangement to work very well (96% agreed) and the time windows and the exam time was considered to be sufficiently long (93% and 99% agreed). The students were encouraged to study between the attempts, but there were no set technical limitations to prevent them from retaking anytime. According to their answers, 69 % (49 respondents) claimed that they had studied between the attempts. Since there were 90-120 student how retook the exam, this means that less than half of them actually did study more between the attempts. The possibility to retake the week exams reduced stress (97% of the respondents). Only a few students (4%) would have preferred to take the traditional exam scored by the teacher, whereas vast majority (85%) disagreed with that idea.

In the open-ended questions, the students were asked “*What was good about these weekly exam arrangements?”* and “*What could be improved in these weekly exam arrangements?*” The answers were analysed and categorized. It was counted, which issues the students brought up and how many times. Only the top four are presented here for both questions. The results indicate that in this exam implementation students valued: improved learning (21 respondents), flexibility (20), reduced stress (15), and immediate feedback (13). According to their answers to question “*What would you improve?*” they would like to improve: Nothing (36 respondents), point loss due to typing/rounding errors (12), more immediate right solutions to problems (8) and tips between the attempts (3). The rounding errors were taken into account in advance by giving exact instructions how to fill in the answers to the questions. This doesn’t unfortunately help to typing errors which easily led to total point loss to that question. What comes to right answers and solution methods, here we needed to balance between learning and assessing. It was chosen that the solution videos were available only after the exam was closed, not immediately after a student had used his/her last attempt. This was a compromise to reduce possibility to use peer’s Moodle account to watch the solution video before own attempt. For learning, some tips or even immediate release of the solution videos would be beneficial, of course.

4 SUMMARY

Automatically scored, recurring weekly exams were piloted in an online engineering mechanics course offered nationally through the Moodle platform. Most students took more than one attempt in the exams, and the majority of students who initially scored low points showed improvement in subsequent attempts. A survey of student feedback found that vast majority of students agreed that this exam arrangement worked well and that retakes reduced stress, was flexible and improved their learning experience and learning outcomes. Almost no one would like to change back to one-attempt exam checked by the instructor.

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MANAGEMENT EDUCATION IN AN ENGINEERING ENVIRONMENT. THE CASE OF BME.

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Conference Key Areas: *Engineering Skills and Competences, Lifelong Learning for a more sustainable world, Addressing the challenges of Climate Change and Sustainability*

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***Keywords**: management education, interdisciplinary skills and competences, sustainability transition, time-series analysis, decision support*

ABSTRACT

Engineering higher education institutes need to integrate new skills and competences into their practice and curricula to accelerate the sustainability transition.

This paper introduces the interdisciplinary upskilling of engineering students enrolled in engineering programs at the Budapest University of Technology and Economics (BME) and which has been provided by the Faculty of Economic and Social Sciences (GTK) since 1998. The BME GTK delivers an educational experience that fits into the environment defined by the engineering faculties at BME. The BME GTK has experience of more than a quarter of a century in engineering education related to socio-economic and management upskilling. This experience may contribute to the common knowledge of engineering education development solutions in the area of sustainability transition.

This study focuses on assessing the socio-economic and management related courses of engineering students at BME provided by the nine departments of the GTK. The analyses examine the non-engineering skills of BME engineering students over the past ten years. The sample includes all the compulsory and elective courses available for engineering students. Based on the assessment results, the most significant management and socio-economic courses, and the related non-engineering interdisciplinary skills, both in bachelor and master levels, between 2012 and 2022 can be identified. The analyses allows the monitoring of management education's role in an engineering environment in the last decade. Furthermore, considering sustainability challenges, it provides an excellent basis for strategic decisions on future educational development.

1 INTRODUCTION

1.1 Management education in an engineering environment

Due to the impact of several unsustainable socio-economic activities related to the natural environment, our present life is undergoing several reversible or irreversible transformations. Innovation can be one of the main drivers in implementing the necessary economic transition; thus, engineering has a crucial role in addressing sustainability challenges. Considering the roots of the radical changes and related challenges, engineering education can play a pivotal role in fostering the path toward a sustainable future (Annan-Diab and Molinari 2017). Modern engineering education needs to deal with multiskilling, disciplinary broadening, innovative problem-solving, and system-thinking educational solutions to be able to adapt to diverse challenges (Van den Beemt et al. 2017; Marques 2008) as expected by engineering practice (Lattuca et al. 2017). The Budapest University of Technology and Economics (BME) was founded in 1782, and ever since, it has continued to be Hungary's leading higher education institute; it's operation and high-standard academic achievement significantly contribute to the economic performance of Hungary through the engineers, scientists, and economic experts that graduate from the university. The BME Faculty of Economic and Social Sciences (GTK) delivers an educational experience that fits into the environment defined by the engineering faculties at BME. The close cooperation with the engineering and natural science faculties can enhance the synergies between technology, economics, and social sciences and also motivates the integration of innovative solutions into the curricula that can foster the practical implementation of interdisciplinary engineering education. BME GTK traces its roots back to a rich tradition through the work of several ground-breaking scientists and departments which focus on organisational and business studies, finance, production and operation management, sustainability, and engineering economics. This journey started with the launch of the postgraduate economic department in 1914 through the establishment of the Faculty of Economic and Social Sciences (GTK) in 1998, and up to 2000 since when the name of the university itself has been a sign of its commitment to university level economics and business education (BME GTK, 2022).

1.2 Interdisciplinary courses for engineering students

The BME GTK has provided interdisciplinary courses since the beginning. This study focuses on introducing and assessing the socio-economic and management-related courses of engineering students at BME provided by the nine departments of the GTK. Two GTK interdisciplinary clusters were developed based on the entire Bachelor and Master course list supplied for engineering students between 2012-2022. Fig.1. introduces the nine GTK interdisciplinary bachelor course clusters. Most bachelor courses can be grouped into four clusters (Sustainability and Climate Change, Psychology and Ergonomics, Business and Management and Communication).

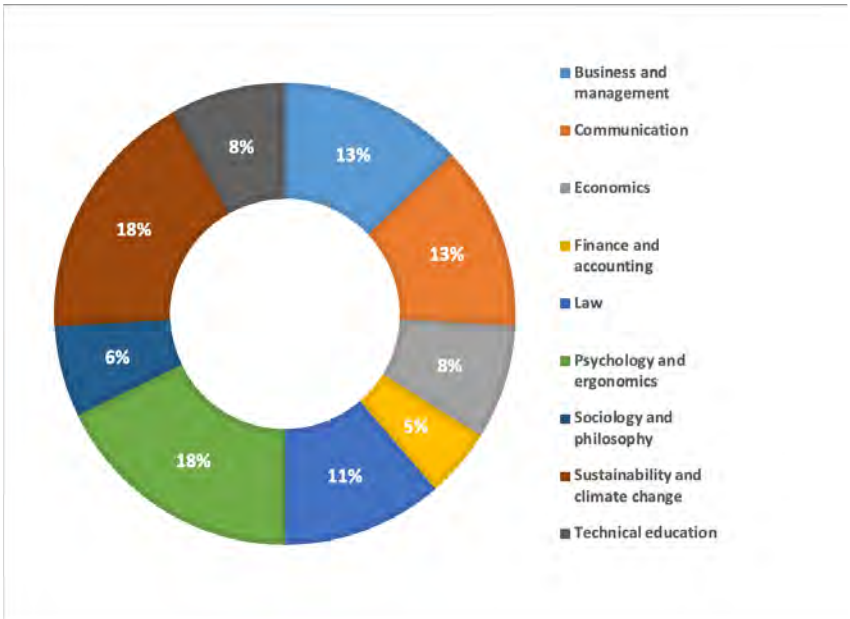

Fig. 1. Top 10 GTK BSc interdisciplinary courses between 2012 and 2022 (n=82446 students)

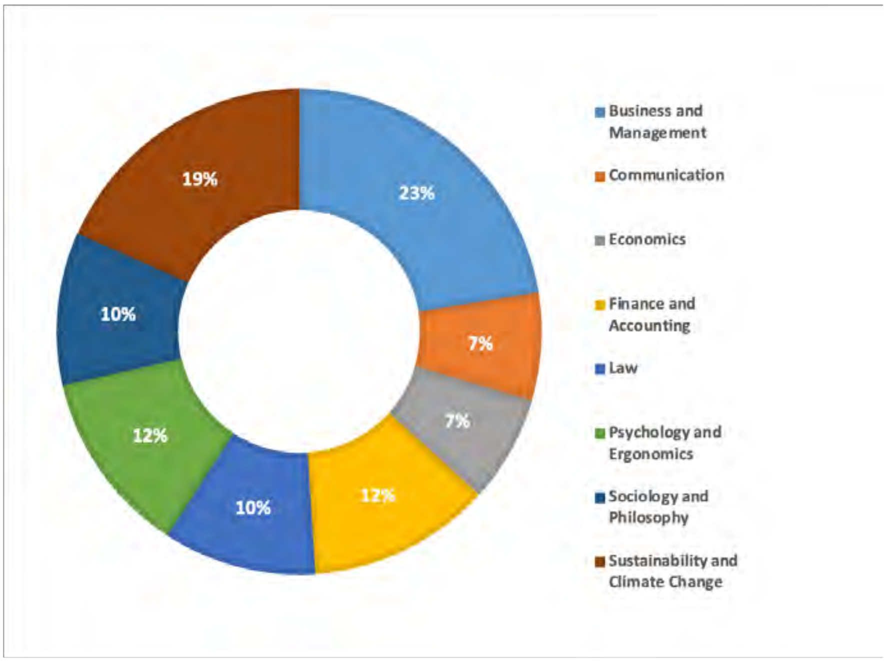

Fig. 2. Top 10 GTK MSc interdisciplinary courses between 2012 and 2022 (n=17196 students)

Fig.2. highlights the eight GTK's interdisciplinary master course clusters. More than half of the master courses available for engineering students belong to three clusters (Management and Business, Sustainability and Climate Change, and Psychology and Ergonomics). Six new master courses have been started and opened for engineering students in the last five years. Four of the courses belong to the Management and Business (e.g., Business Data Visualisation), and the other two to the Sustainability and Climate Change (Circular Economy) and Law (The Legal Framework of Autonomous Vehicles) course clusters.

2 METHODOLOGY

2.1 Quantitative analysis

The analysis examines the non-engineering skills of BME engineering students through GTK's interdisciplinary courses over the past ten years. This practice-oriented study aims to provide a quantitative analysis based on the related course data between 2012-2022. Descriptive statistics, ranking, and exploratory data analysis were used for the quantitative analysis. The data were retrieved from the Neptun system, which is an educational administration system and stores the required course and student-related data for the student's performance evaluation. The sample includes all the compulsory and elective courses available for engineering students at the bachelor and master levels. Considering the curricula on bachelor or master levels the compulsory courses mean the core units and in case of the elective courses the students may choose course units from the entire university portfolio. All eight BME faculties were involved in the analysis, namely the Faculty of Civil Engineering (ÉMK), Faculty of Mechanical Engineering (GPK), Faculty of Architecture (ÉPK), Faculty of Chemical Technology and Biotechnology (VBK), Faculty of Electrical Engineering and Informatics (VIK), Faculty of Transportation Engineering and Vehicle Engineering (KJK), Faculty of Natural Sciences (TTK), Faculty of Economic and Social Sciences (GTK). The students enrolled to GTK were involved and examined only in the case of Engineering and Management Bachelor and Master programs.

3 RESULTS

3.1 All courses provided by GTK for engineering students (2012-2022)

Based on the data retrieved from the Neptun system, nearly 3000 courses were analyzed between 2012 and 2022. The Neptun system is an online administration system that holds all academic data and personal information of the students, teachers, and courses, it is provided by the Central Academic Office of BME. 71% are Bachelor's and 29% are Master's courses out of the 2917 courses provided by GTK for engineering students in this period. Fig. 3. shows the number of students enrolled in non-engineering courses provided by GTK faculties. Over the ten years examined, this represents a total of 219 606 students of the engineering programs. More than 60% of the examined students study engineering in two faculties. 38% of the students pertains to the Faculty of Electrical Engineering and Informatics (VIK), and 26% of the students to the Faculty of Mechanical Engineering (GPK). Considering the course type, Fig.4. shows that most courses are elective (58%), and the proportion of compulsory courses is 42%. In the case of four faculties (VIK, GPK, ÉPK and TTK), the ratio of compulsory and elective courses is evenly balanced. The majority of compulsory courses are taken at the ÉMK and VBK. Two other faculties (GTK and KJK) can be characterized with most elective courses.

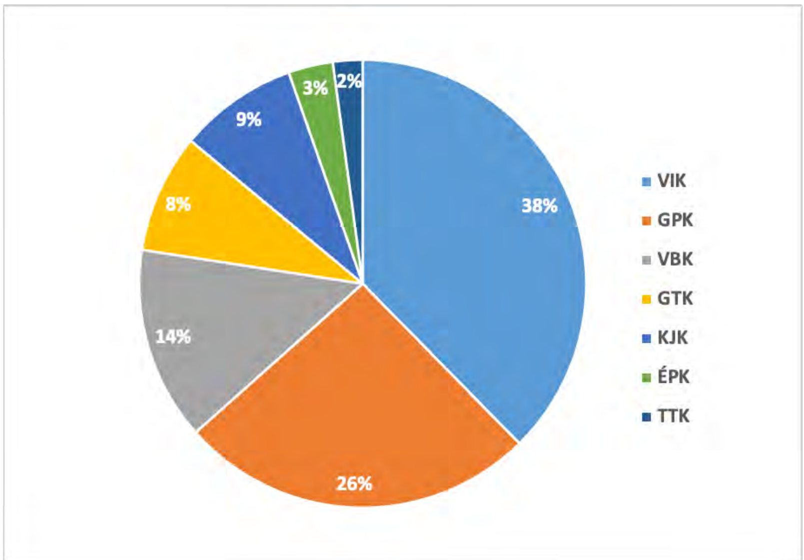

Fig. 3. Percentage of students enrolled in non-engineering courses provided by GTK between 2012 and 2022 by faculties (n=219606 students)

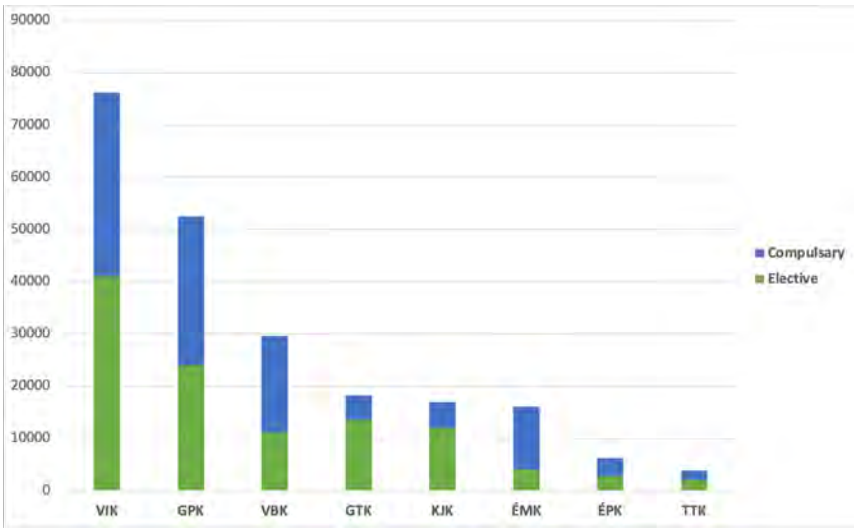

Fig. 4. Percentage of students enrolled in non-engineering courses provided by GTK between 2012 and 2022 by faculties and by course type (n=219606 students)

Fig.5. highlights the non-engineering courses provided by GTK at bachelor (BSc) and master (MSc) levels by faculties. The number of students in bachelor non-engineering courses is significantly higher than in master level. 76% of the enrolled students study for a Bachelor degree, and 24% study for a Master degree. These data contain only those GTK students who study engineering and management, the only engineering program at GTK. Most of the Faculty of Electrical Engineering and Informatics (VIK) students participate in both levels of education. Figure 5 shows that taking into account the Faculty of Mechanical Engineering (GPK), the negative change is proportionally more significant for the selected subjects in the Master's programs compared to the Bachelor's programs. In the case of the Faculty of Architecture (ÉPK), students tend to prefer the Master's courses at the GTK.

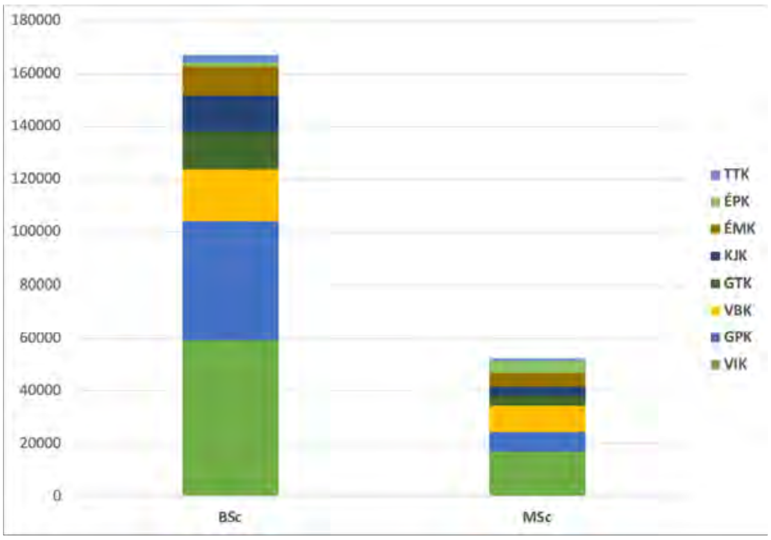

Fig. 5. Number of students enrolled in non-engineering courses provided by GTK on BSc and MSc level between 2012 and 2022 by faculties (n=219606 students)

3.2 Top 5 interdisciplinary courses on Bachelor and Master levels (2012-2022)

After evaluating the entire sample, courses unavailable in each academic year of the 2012-22 period were excluded. The Bachelor and Master courses were ranked based on the total number of enrolled students in the whole examined period. The rankings were developed separately for the two levels of education, and the top 5 interdisciplinary courses were defined on BSc (n=82446 students) and MSc level (n=17196 students).

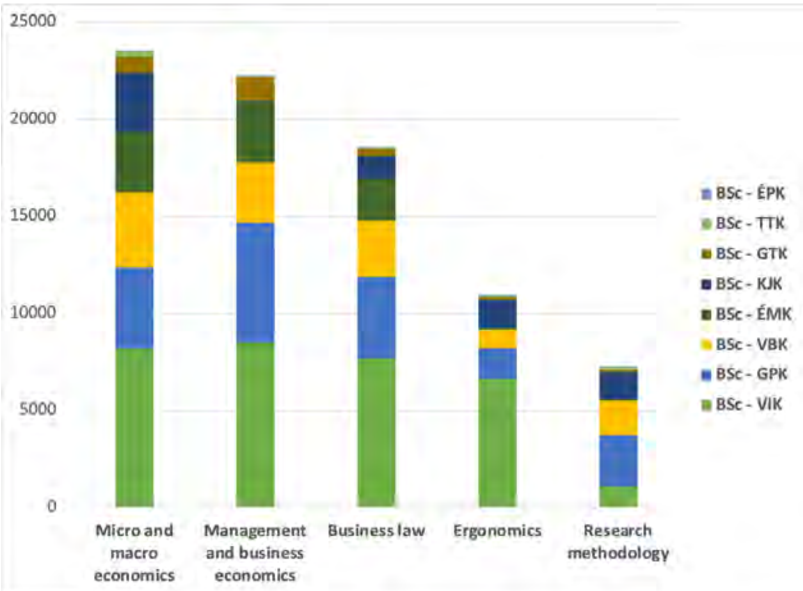

Fig. 6. Top 5 GTK BSc interdisciplinary courses between 2012 and 2022 (n=82446 students)

Fig.6. highlights the top 5 bachelor courses (1. Micro and macroeconomics; 2. Management and business economics; 3. Business law; 4. Ergonomics; 5. Research methodology) which pertain to four different GTK bachelor interdisciplinary clusters (Economics, Business and Management, Psychology and Ergonomics).

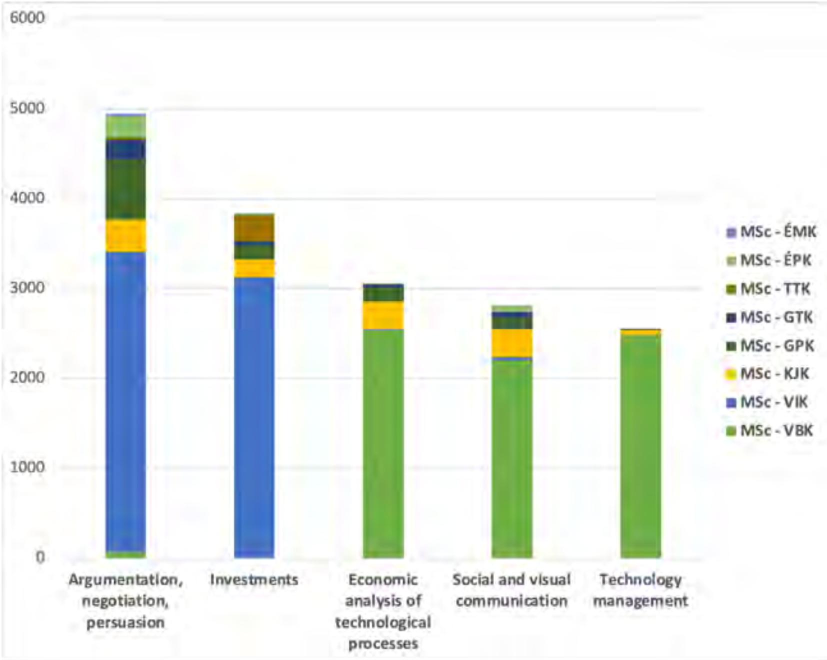

Fig. 7. Top 5 GTK MSc interdisciplinary courses between 2012 and 2022 (n=17196 students)

Fig.7. shows the top 5 master courses (1. Argumentation, Negotiation, Persuasion; 2. Investments; 3. Economic Analysis of Technological Process; 4. Social and Visual Communication; 5. Technology Management) which pertain to three different GTK master interdisciplinary clusters (Communication, Finance and Accounting, Economics and Business and Management). The most popular courses are Argumentation, Negotiation, Persuasion, and Investment for the students of the Faculty of Electrical Engineering and Informatics (VIK). The Faculty of Chemical Technology and Biotechnology (VBK) students are more interested in Economic Analysis of Technological Processes, Technology Management, and Social and Visual Communication. Considering the GTK's MSc and BSc interdisciplinary course clusters (see 1.2) it shows that a wide range of Sustainability and Climate Change related courses are available in both evaluated categories; none of them can be found in the top 5 courses. Further evaluation is necessary to assess how sustainability skills are embedded into the course content and how course units related to the sustainability transition can be supported to enhance sustainability skills in engineering education.

4 SUMMARY AND ACKNOWLEDGMENTS

Engineering and non-engineering higher education institutes (HEIs) need to integrate new skills and competences into their practice and curricula to accelerate the transition to a greener economy and society. The recent practice-oriented study introduced how a one-decade-long management education in engineering could enhance the inter and multidisciplinary skill and competence development of the engineering and natural science students at the Budapest University of Technology and Economics. Based on the results, it can be stated that the BME GTK has made relevant progress in developing an inter- and multidisciplinary educational portfolio development over the past decade. The analysis, which embraces all relevant courses and engineering specializations, allowed monitoring of the management education's role in an engineering environment. The results can also provide solid foundations for strategic decisions on future educational development and for the successful adaptation to the emerging challenges and opportunities of our changing world. In the long term, BME GTK aspires to support the approach of engineering education to be transformed to prepare future engineers to face successfully sustainability challenges.

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INSTRUCTORS´ EXPECTATIONS AND OBJECTIVES FOR INTEGRATING SUSTAINABLE DEVELOPMENT AND ETHICAL ISSUES INTO THE CURRICULUM

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Conference Key Areas: *Embedding Sustainability and Ethics in the Curriculum*
Keywords: *Sustainable development, ethics, curriculum*

ABSTRACT

The integration of sustainable development and ethical issues into the curriculum is increasingly important in higher education. The study surveyed 17 instructors in ICT

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engineering education at Lapland University of Applied Sciences who were involved in curriculum development to explore their expectations and objectives in integrating sustainable development and ethical issues into their courses. Although most instructors had a good understanding of sustainable development and ethical issues, not all saw them as relevant to their courses. Those who did incorporate these themes focused on topics such as energy conservation, social sustainability, and sustainability and ethics in solutions. However, almost half of the instructors did not plan to incorporate ethical issues into their courses, and those who did focus on copyright, artificial intelligence, and source criticism. Instructors expressed the need for themed discussion sessions and expert lectures to enhance their knowledge and skills. The study's results suggest the need for more effective strategies to incorporate sustainable development and ethical issues into ICT education. The findings of this study could support academics in their ongoing efforts to incorporate ethical and sustainable development concerns into their curricula

1 INTRODUCTION

The integration of sustainable development and ethical issues into higher education has been recognized as essential for a long time (Menon & Suresh 2020). However, incorporating these themes into specific academic disciplines, such as ICT-engineering education, can be challenging. The research aims to explore the expectations and objectives of ICT-engineering instructors in integrating sustainable development and ethical issues into the curriculum.

The rectors' conference of Finnish Universities of applied sciences (ARENE 2022) has published recommendations for shared competences, including competencies for ethics and sustainable development. According to ARENE, graduating students should adhere to the ethical principles and values of their profession, taking into account the principles of equality and non-discrimination. They should also be familiar with the principles of sustainable development, promote their implementation, and act responsibly as professionals and members of society.

Integrating concepts of sustainability and ethics into the curriculum requires a predetermined plan. Lundqvist (2016) emphasizes the importance of integrating ethics in courses on engineering topics, using cases to teach ethics effectively. Park et al. (2022) argue that instructors must be open to new methods and master sustainable development approaches to provide guidance and solution-based processes. Segalàs et al. (2010) suggest that cognitive learning of sustainable development increases through experiential active learning, which can be implemented using a constructive and community-oriented pedagogical approach.

There are several approaches to incorporating sustainable development and ethics into engineering education programs, such as micro-curriculum (Ashraf 2020), project-based learning, multicultural and multidisciplinary teamwork (Duarte et al., 2020), and separate modules for first-year students (Amashi et al., 2021). Further, ethics has been taught through asynchronous videos as part of a PBL implementation (Koppikar et al. (2022) and with challenge-based learning involving students in case manipulation (Bombaerts et al. 2021). Overall, Børsen et al. (2021) suggests involving students in the teaching of sustainable development and ethics, doing so by utilizing the methods of active pedagogy and by linking the content close to real life.

In conclusion, integrating sustainable development and ethical issues into higher education is essential. However, incorporating these themes into specific academic disciplines, such as ICT-engineering education, can be challenging. It requires a predetermined plan, and instructors must be open to new methods and master sustainable development approaches. There are several approaches to incorporating sustainable development and ethics into engineering education programs, and graduating students should adhere to the ethical principles and values of their profession, take into account the principles of equality and non-discrimination, and be familiar with the principles of sustainable development. Instructors' knowledge of these topics may require further development, and emphasizing their importance may encourage changes in attitudes towards these subject areas.

Previous research (Angelva et al. 2023) prior to the research described in this paper has mapped students' perceptions of ethics and sustainable development, but it is equally important to study the perspectives and prejudices of the professors and lecturers responsible for planning curriculum and teaching. Instructors' knowledge of these topics may require further development, and emphasizing their importance may encourage changes in attitudes towards these subject areas. The attitudes of instructors and supervisors can significantly influence students' motivation to think about these themes in all areas of their education and understand them as fundamental elements of their professional competence.

In the next chapter, we will first provide a summary of the initial study that collected students' perceptions and expectations towards ethics and sustainable development. Subsequently, we will present the methodology of the current study and the results obtained. We will then discuss the implications of these findings and provide suggestions for incorporating sustainable development and ethical issues into the curriculum.

2 METHODOLOGY

All 21 ICT instructors who were involved in the curriculum development process for the ICT engineering education in Lapland University of Applied Sciences in Finland were invited to the present study. In this process, one of the most important development targets was to try to include the perspectives of sustainable development and ethics in learning. The development was preceded by a survey collecting students' thoughts and expectations (Angelva et al. 2023), the results of which were tried to be included in the implementation plans of the curriculum. An earlier study concluded that students have a basic understanding of both themes, but also suggested practical examples, cross-cutting themes, and learning tasks to effectively integrate ethics and sustainable development into the curriculum.

In this study, a survey methodology was utilized to gather data from participants regarding their experiences with the topic of interest. To facilitate the comparison of teachers' thoughts concerning students' responses, it was decided to examine both themes through a similar set of questions. In addition, the teachers were asked about their intentions and plans for the contents of the study courses, as well as their wishes for the development of competence regarding these themes.

The survey was conducted using the Webropol 3.0 survey and reporting tool. The survey comprised a total of 10 questions. The first two questions aimed to assess the participants' understanding of key concepts such as sustainability and ethics. Respondents were asked to provide their answers using a sliding scale ranging from 1 to 10. Subsequently, participants evaluated the degree of integration of education for sustainable development by selecting the most appropriate option from the provided choices, as illustrated in Figure 1.

Open-ended questions were employed to explore respondents' perspectives on sustainable development learning tasks/curriculum for students and the type of training instructors themselves would prefer to receive. The participants' understanding of concepts such as responsibility and respect was assessed again using a sliding scale of 1 to 10. Similarly, open-ended questions were utilized to gather information on instructors' plans for organizing learning tasks/curriculum for students and their preferences for internal training on these topics.

Thematic analysis was employed to analyze the collected responses (Vaismoradi, Turunen, and Bondas, 2013). The data underwent multiple iterations of analysis, with the extraction of general concepts and meanings through an inductive reasoning process. The responses were subjected to content analysis using open coding, where analysis units were extracted from the text. These units were then classified and grouped into thematic areas. The analysis aimed to identify and categorize common themes across the responses. Frequencies were calculated for each theme to determine their occurrence. Due to the small number of responses, further grouping of the categories was deemed unnecessary to maintain the integrity of the content.

The survey link was distributed via email to the participants, and a one-week period was provided for response submission. The response rate for the survey was 81% (17 participants)

3 RESULTS

3.1 Sustainable development

In their own opinion, the respondents knew the terms sustainable development well on a sliding scale of 1-10, with the median being 8.0. Out of the participants, 7 (41.2 %) indicated a comprehension level of 9-10, while 6 (35.3 %) responded at levels 7-8. The minimum score of 3 was recorded by 1 participant (5.9%).

Regarding the question about how well the degree programme curriculum integrates sustainable development, as evaluated by the CDIO optional standard 3.0, Figure 1 shows that most of the instructors' responses fell into the 1-2 rating categories.

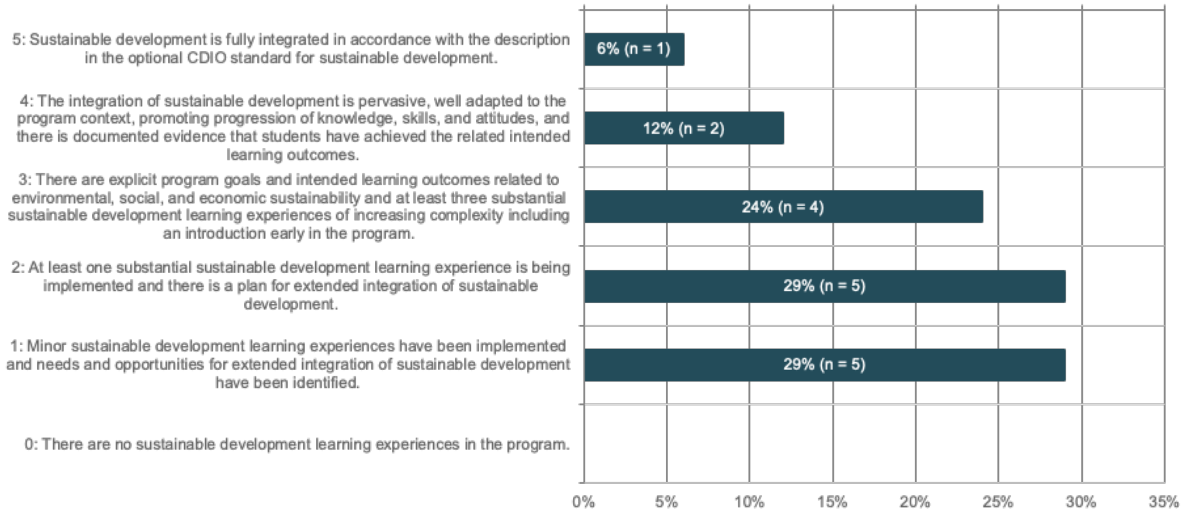

Fig.1. Instructors' assessment of the level of inclusion of sustainable development on the CDIO the optional standards scale.

The option that suggested no sustainable development learning experiences, was not chosen by any of the respondents and the level 5 option with fully integrated was answered by 1 (6%) of the respondents. Since the sustainable development was contextualized with a description according to the CDIO standard in the initial question, which also mentioned the term CDIO, the instructors were probed regarding their familiarity with this term. The responses were elicited using a sliding scale ranging from 1 to 10, and the instructors' ratings were predominantly within the 5-10 range, with levels 10 and 9 receiving the highest number of responses (both 23.5%). Four responses (23.5%) were missing from the dataset.

In an open question, instructors were asked what kind of sustainable development learning experiences they have offered or plan to offer. The instructors listed the following perspectives: learning assignments and projects related to the consideration and ideation of sustainable development perspectives in system development solutions, recommended programming practices, energy saving, and social sustainability themes, such as respect, consideration, and inclusion of others.

When the instructors were asked about their preferences regarding assignments on the theme of sustainable development, they expressed a desire to hear expert lectures and learn about the impact of the IT sector on sustainable development. Additionally, they emphasized the importance of topics such as achieving energy self-sufficiency and ensuring the security of supply. The instructors also expressed a need for themed internal discussion sessions on the topic. However, not all teachers and supervisors considered it necessary to include these concepts in the courses they taught or supervised. One comment suggested that sustainable development should not be conflated with regular course content and that a separate study course should be offered to students.

3.2 Ethical perspectives

Regarding ethical perspectives, 9 (52.9%) of the respondents felt that they understood the meaning of the term responsibility on a scale of 1-10 at levels 9-10. The minimum value was 3, which was answered by 1 (5.9 %) respondent. The corresponding number of answers regarding the term respect was 12 (70.6 %) respondents at level 9-10, the minimum value was 6, which was answered by 1 (5.9 %) respondent.

Ethics-related learning tasks were offered or planned to be offered as follows: Copyright in materials (3 mentions) and program codes, using artificial intelligence and challenges (2 mentions), source criticism (2 mentions), license terms, discussions, product compliance, and open materials and interfaces. However, 8 respondents (47.1 %) answered that they do not plan to organize any learning experience related to the theme and there were 3 (17.6 %) missing answers.

Regarding ethics and ethical perspectives, the instructors wanted themed discussions and themed days (2 mentions), expert lectures, independent study material and programming ethics. A total of 3 (17.6 %) instructors saw that there is no need to handle the theme as personnel training and 1 (5.9 %) could not say and 3 (17.6 %) missing answers.

Finally, the set of questions included an open question that was answered by 3 (17.6%) respondents. The themes were perceived as significant, and it was anticipated to receive further training. The importance of sustainable development in the future of the degree programme should be considered and the themes should also be made part of everyday life.

4 SUMMARY AND ACKNOWLEDGMENTS

Integrating Sustainable Development Goals (SDGs) and ethics into engineering curricula is an effective way to develop socially responsible and ethically aware engineers who are equipped to design and implement sustainable solutions to global challenges. By integrating SDGs and ethics, engineering curricula can provide a more holistic education that emphasizes the importance of considering social and environmental impacts in engineering practice.

This study examined the instructors' attitudes and plans for integrating sustainable development and ethical issues into their courses. The study's results reveal that while the instructors recognize the importance of sustainable development and ethical issues, they do not always see the relevance of these themes to their courses. This attitude may create resistance to incorporating these themes into the curriculum. The concepts of sustainable development and ethics are mainly well-known by instructors.

The instructors had used or planned sustainable development learning assignments, e.g., consideration of perspectives in system solutions, energy saving, and social sustainability themes. One way to integrate SDGs and ethics into engineering curricula is to incorporate them into existing technical courses. For example, in general, in the context of engineering education, a course on environmental engineering could include discussions on how engineering solutions can contribute to achieving SDG targets such as clean water and sanitation or sustainable cities and communities. Similarly, a course on engineering design could incorporate ethical considerations into design decisions, such as considering the potential social and environmental impacts of a design. Another approach is to create dedicated courses or modules that focus specifically on SDGs and ethics. These courses could cover topics such as the ethical implications of engineering practice, the role of engineering in achieving sustainable development goals, and how to design solutions that prioritize social and environmental sustainability. The competence of sustainable development may be promoted by using real-life events as context (Leal Filho et al. 2022). It is also important to integrate SDGs and ethics throughout the curriculum by emphasizing their importance in engineering practice and by modeling ethical behavior in the classroom. This can include promoting a culture of ethical inquiry and reflection, encouraging open dialogue on ethical issues, and providing opportunities for students to engage in ethical decision-making exercises. Further, ethics scenarios can be implemented with the assistance of external stakeholders and guest speakers (Martin et al. 2021).

However, integrating SDGs and ethics into engineering curricula is not without its challenges. As mentioned earlier, a lack of expertise among engineering faculty in SDGs and ethics can be a major challenge. However, instructors play a key role in the successful integration of sustainable development approaches into the curriculum and course content (Park et al. 2022). Therefore, professional development opportunities and faculty support are essential for successful integration. Additionally, there may be a need for additional resources to develop new curricular materials or to redesign existing courses. According to the findings of the current study, not all instructors saw the themes of sustainable development and ethics as relevant to themselves or the course they taught. Furthermore, almost half of the instructors answered that they do not intend to organize learning assignments related to ethics. If assignments were organized, they were focused e.g., on copyrights, the use of artificial intelligence, or source criticism.

Although, based on this study, the concepts are known and seen as important, it is still more challenging to include the perspectives in one's subject area. In dealing with these issues, one could see similarities with the study by Lundqvist (2016) discusses the challenges faced during the integration process and provides recommendations for supporting program directors and teachers to accomplish such a change. The study also highlights the challenges in integrating ethics, including a lack of understanding from program directors and teachers, and the need for support and competence development for teachers (Lundqvist 2016). A successful change process can be established by using Kotter's (2007) eight steps, along with individual program directors’ and teachers' engagement and involvement. A commitment from management can facilitate the change process, and instructors may need support to become comfortable with integrating ethics into their courses (Lundqvist 2016). Kotter (2007) lists eight steps starting with steps 1) Create a sense of urgency and 2) Create a Guiding Coalition and ending with steps 7) Build on the change and 8) Anchor the changes in corporate culture. The research presented in this paper can be considered to represent Kotter's (2007) phase 1, where belief in the importance of change for the organization is built. Further, the instructors suggested themed discussion sessions to develop skills along with expert lectures, which can be compared to Kotter's phase 2. In it, the change process is promoted by assembling a team with the right knowledge, skills, and possibilities to support and accelerate. A commitment from management can facilitate the change process, and teachers may need support to become comfortable with integrating ethics into their courses (Lundqvist 2016).

In conclusion, integrating SDGs and ethics into engineering curricula is essential for preparing future engineers to be socially responsible and ethically aware professionals who can contribute to achieving sustainable development goals. This can be achieved through incorporation into technical courses, the creation of dedicated courses or modules, and program-wide emphasis on SDGs and ethics. Practitioners can use the findings of the current study to develop more effective strategies for integrating sustainable development and ethical issues into ICT education. The study's implications may have an impact on society, education, and global initiatives to promote sustainable development and ethical behaviour.

This paper has some limitations. The sample size of the study is small, although the participation rate is high 17/21 (81%). The research was done by translating the English questions into Finnish. The answers in Finnish have been translated into English for this publication, and it is possible that in some cases there may have been inaccuracies in the translations. The authors of the survey are also the authors of the publication and are also among the respondents. The influence of the survey authors on the results cannot, therefore, be excluded. The analysis of the answers and their classification was done by the authors and is possibly subjective. The published conclusions and the choice of operational development measures are also influenced by the fact that the authors have development tasks related to the organization's teaching and therefore also partially responsible for the implementation of the measures. This may have had an impact on the analysis.

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WORK PERFORMANCE EVALUATION AS A MOTIVATIONAL APPROACH FOR EARLY-CAREER SELF MANAGEMENT

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Conference Key Areas: Engineering Skills and Competences, Innovative Teaching, Curriculum Development
Keywords: Soft skills and competences; Transition to labour market; Career development; Engine4STEMers.

ABSTRACT

This article presents the main characteristics of an academic experience based on the concept of "work performance evaluation", whose objective is to facilitate a smooth transition to the technological labor market. Its aim is to motivate STEM graduates to

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acquire relevant early professional skills and a self-management attitude in their careers. The results of a satisfaction survey after a pilot course experience with 30 bachelor engineering students at UPC, within the framework of the Engine4STEMers project [Torres, 2022], are also presented. This experience starts with the concept of "direction of service" and the rapid change in attitude and work methodology that a STEM graduate must undertake to evolve from a user culture (student) to a service provider culture (employee or entrepreneur). Then, based on open class discussions and as an exercise in self-reflection and motivation, students develop a list of expected differences in "job performance evaluation" between academia and the job market. This help students visualize the need to readapt their work methodology and attitude when they enrol in their first jobs.

1 INTRODUCTION

1.1 Context and motivation

The current fast-changing and highly demanding tech labour market requires STEM graduates to undertake a rapid readaptation in attitude and work methodology to evolve from a user culture (student) to a service provider culture (employee or entrepreneur) [Torres, 1998][Torres, 2022]. In general, employers give increasing importance to the development of social, emotional and highly cognitive skills [Mckinsey, 2018][Gordon, 2019]. In this sense, it is of major importance to develop educational initiatives where last-year bachelor students can reflect on their current set of skills: first to improve their self-esteem, and later to find out what competences they need to develop or improve in their near professional future. However, to foster an effective change in the mindset of STEM students, it is even more important to motivate them to acquire such skills as they transition into the job market and to further develop them on a lifelong learning basis [CEU, 2018].

The teaching and learning motivational experience presented in this paper has been undertaken within a 3 ECTS pilot course at UPC titled "*Leadership and Professional Development in Engineering".* The content of this elective course is listed in Table I. This elective subject begins by presenting the concepts of planning and career development in the field of engineering. A special emphasis is dedicated to the transition stage between academic and professional activity, focusing on the essential aspects, both for a correct entry into the world of work [Torres, 2022], and for the subsequent evolution of the professional career in engineering [Torres, 1998]. Focusing on junior engineer needs, the main personal and professional development techniques (PPDT) are presented. Basically, they start with the junior engineer as executors of tasks, to continue with a larger focus on management and leadership functions as the young graduate evolves to the role of an expert senior engineer [Mckinsey, 2018][Gordon, 2019]. Finally, the main entry-level techniques and skills required for successful career development in engineering are discussed.

Table 1 Leadership and Professional Development in Engineering

1. The concept of a professional career in engineering a. Skills developed in the academic stage b. The transition from the academic stage to the professional stage c. Evolution of the engineer: from executor to manager and leader
2. The junior engineer: the first jobs a. Initiative and leadership in the early stages b. Evaluation of professional performance in engineering c. Main considerations and mistakes to avoid a. d. Transversal competencies: action oriented to results
3. Professional career development techniques a. The management of self: self-knowledge, self-esteem and self-management b. Personal qualities: values, responsibility and character c. Communication, perception and deception d. Interpersonal relationships: from me to us e. Proactivity, criteria and maturity (common sense) f. Decision making in a VUCA environment g. Creation and exploitation of opportunities h. Personal growth: 10 fundamental characteristics

2 METHODOLOGY AND TOPICS FOR CLASSROOM DISCUSSION

2.1 Pilot course methodology

Figure 1 shows a taxonomy of the main concepts addressed by the pilot course and how they are related. Self-awareness is the core skill that enables professional career self-management. It starts with a discussion in class on what are the general transversal skills that students have developed within the academy (Fig. 2). This awareness to improve students' self-esteem and makes them more receptive to address what are the competences that require further development for a successful job market entry. Here, students are told that these general competencies provided by the STEM degrees, along with the general and specialized knowledge already acquired, are highly valued by employers in the technology job market. Improving self-esteem, as done in this first part, is important to avoid a defensive or reactive behaviour by the students later on when their weakness are exposed. This makes them to better accept the need for change when they are told to start the path of personal and professional improvement.

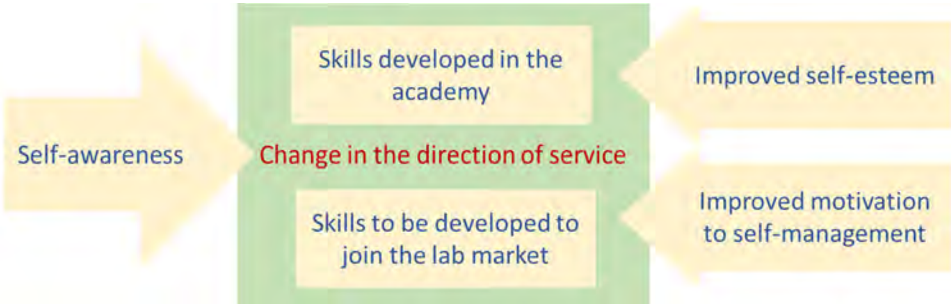

Fig. 1. Flowchart showing the relationship between the main concepts of the pilot course

After this introductory part, the course follows with the concept of **"change in the direction of service"** (from user to service provider) that is used for group discussion to help students visualize the need to undertake a change in the work methodology and attitude in their first jobs (Fig.3) [Torres, 1998][Torres, 2022]. This is in line with how is leadership evolving today to the concept of "servant leadership" where instead of being a manager directing and controlling people, leadership is increasingly understood to be in the service of those they lead [McKinsey, 2022]. These discussions are carried out through various case studies and key questions intended for students to identify the main conceptual differences between tasks performed in academia (as students) and work in the labor market (as professionals). As common sense conclusions, most of the major soft skills concepts emerge spontaneously from these discussions, allowing for a more systematic approach later. The example presented in this paper, is one of the main exercises that have been carried out in the pilot course to illustrate the underlying learning concept derived from the concept of service described in Figure 3.

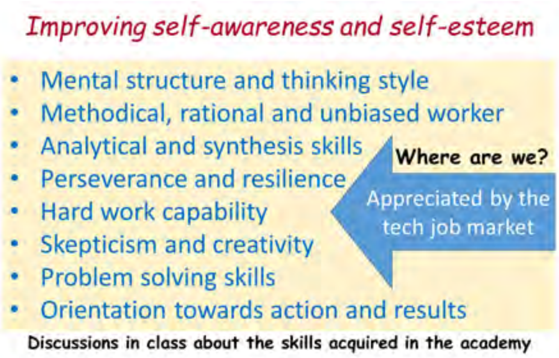

Fig. 2. Competences acquired at the university

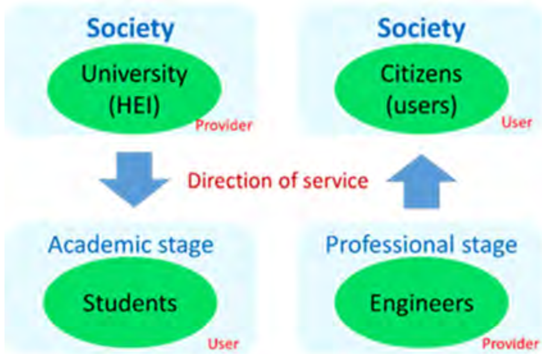

Fig. 3. From user to service provider

2.2 The concept of work performance assessment

The educational experience presented in this paper is based on the statement that students are very familiar with work performance evaluation in the academic environment. In order to foster discussion and contrary to what sometimes they may perceive, students are told that academic evaluation is a very systematic, predictable and fair process. Based on this statement, they are first asked to list and discuss the main features of academic evaluation (Fig. 4). Students are challenged afterward to imagine and discuss what they think the main differences will be when they sign up for their first job. That is, **how is job performance going to be evaluated in the workplace?** It must be pointed out that this approach is not related to formal job performance assessment tools. Instead, the concept of professional reputation, which is prone to different types of biases, is presented as an informal assessment of job performance that has a major impact on career progression. The key importance of this public perception of job performance in career advancement is discussed and emphasized to make students aware of the need to cultivate specific transversal skills. These are presented as personal and professional development tools (PPDT) that act as experience accelerators. The impact of instrumental skills on short-term progress compared to long-term personal and professional growth based on values and principles is discussed as an important conclusion of this exercise.

2.3 Description of the experience: "work performance assessment"

In order to engage students in the topic of interest for discussion, the following statement is formulated: "*Evaluation procedures in the academy are very favorable for the subject under assessment (students)"*. Of course, students are well aware of assessment procedures and their impact on their academic progress. It is clear to them that academic evaluation is quite discrete through exams, subjects, semesters and so on (Fig 5). However, it turns out that, in general, they have paid to them very little attention from a more comprehensive perspective. As a classroom exercise, this counter-intuitive (for them) statement gives an opportunity to list and discuss the main features of formal academic assessment.

- Discreet and objective evaluation (exams, grades)
- Thematic and bounded evaluation
- Known instant and evaluation method
- Possibility of revision, several opportunities
- Method with little inertia, no history (last result)

Fig. 4. Some features of academic evaluation

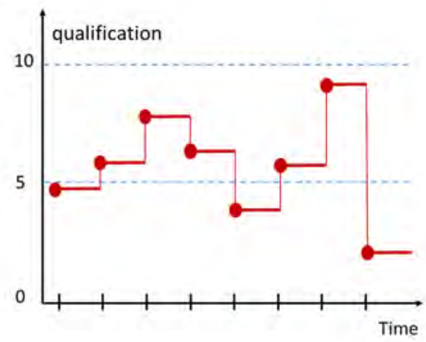

Fig. 5. Academic evaluation is discrete

The initial phase of this exercise reveals a key finding: students possess a thorough understanding of the "rules of the game" and demonstrate a high level of adaptation to academic evaluation procedures, irrespective of their personal agreement or disagreement with the grades they are awarded. Now, the above discussion has led to the following question for when graduates enter the labor market: ***What are the new rules of the game going to be? How will they be evaluated? What changes are necessary to adapt to the new environment?***

The answers discussed in the classroom regarding these questions will be addressed in the next section. However, at this point, it is worth making a clarification to the reader: what has been discussed so far is a very "simplistic" model of evaluation in the academic field, just for the sake of class discussion and student self-reflection. Obviously, the purpose and methodology of academic assessment have a much broader scope when properly analyzed from a holistic perspective in the context of higher education.

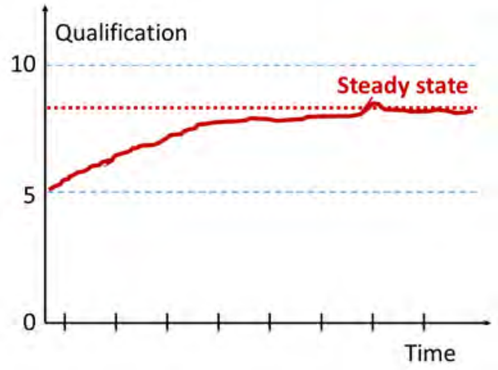

Fig. 6. Model for the "score" evolution at the workplace

- Unknown evaluator
- Unbounded theme content
- Indeterminate evaluation period
- Unknown evaluation method
- Limited revision possibility
- Limited possibility of rectification
- High inertia method

Fig. 7. Some expected features for job performance assessment

2.4 The concept of "job performance evaluation" as a motivational tool

Once the main features of academic assessment have been discussed, students are ready to repeat the exercise on job performance assessment in the workplace. Some ideas easily come out: exams and end-of-semester grades will no longer be issued. However, so far they have paid very little attention, if any, to the fact that there will be some kind of performance evaluation. They also generally haven't thought about what this assessment will look like or what implications it may have for their career progress. Now, the following general assumptions are agreed to focus discussions:

- Somehow, the "company" has a performance assessment ("score") of each employee.
- When hired, the default evaluation score is at least sufficient.
- This assessment evolves over time to a more or less stable state.
- Career progress highly depends on this score.

These simple assumptions are illustrated in the model given in Figure 6. This graphic helps students to figure out what might be the main features of their workplace assessment. To carry out this exercise, it was useful for students to contrast these features with the equivalent concepts discussed in the case of academic evaluation (Fig. 5). Some interesting characteristics of job performance evaluation, as a result of this exercise, are listed in Figure 7. As a result, students came to the conclusion that job performance assessment may be quite unfavorable for the subject under evaluation (the young graduate). Next, students are asked to guess what problems may skew the evaluator's judgment, in what we call **"the imperfect evaluator method".** Some of the issues that have emerged in class are the following:

- The evaluator may have a very sporadic dedication to the evaluation.
- The evaluator may give low priority/importance to evaluation issues.

- The evaluator may have limited knowledge of the employee.
- The evaluator may have limited knowledge of the activity or the topic.
- The evaluator may be influenced by “public opinion”.
- Primary importance may be given to results, regardless of their difficulty.

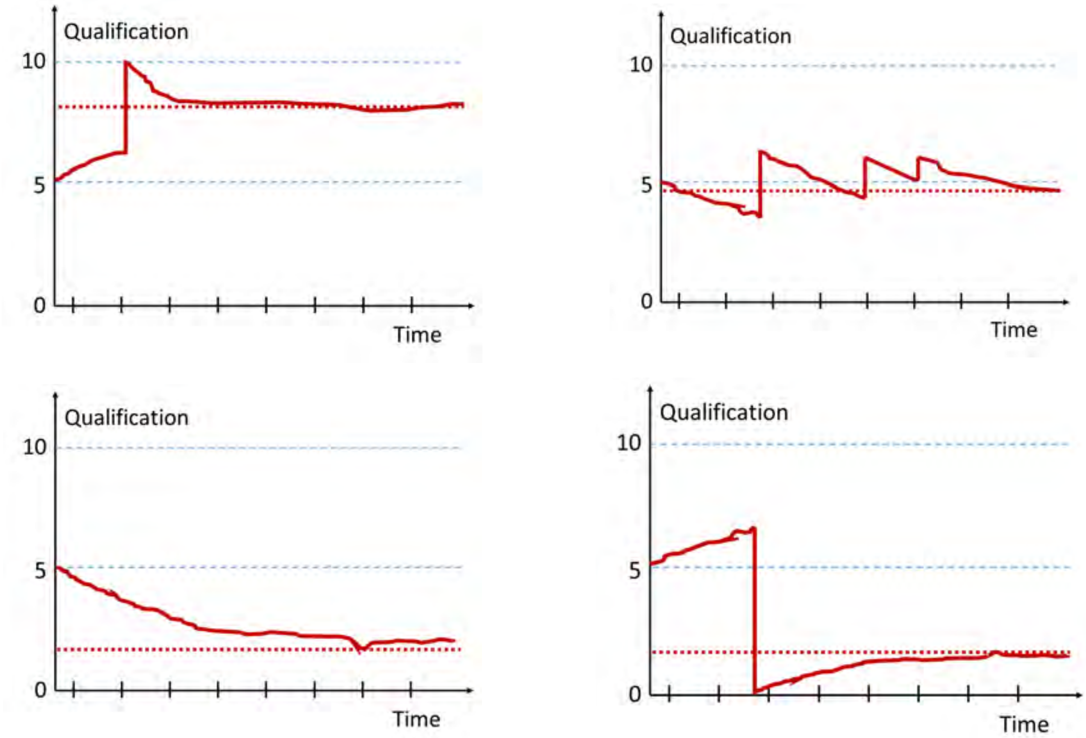

Fig. 8. Extreme career evolution types. From left to right, top-down: “Coca-cola” inventor; isolated lab-rat; lazy guy; crooked guy.

As an important outcome of this exercise, students came to the conclusion that job performance evaluation in the workplace can be quite subjective, biased, and unfair. In any case, they unanimously agree that, in many cases, these biases may be real and that they can greatly condition remuneration, promotion, task assignment, or contract renewal, among others. At this point, the professor clarifies that companies, in their own interest, try to establish systematic, fair, and transparent job performance evaluation procedures. However, they cannot prevent a certain degree of human bias from leaking into these procedures: those in charge rarely have the subject-specific knowledge, motivation, and time to “perfectly” assess the junior engineer's job performance. Therefore, the character of the graduates and the specific results of their projects greatly influence the judgments of the evaluators.

Before moving on, it is also important to point out that the model in Figure 6 is quite simple. However, it allows the students to easily envisage what can be the main traits of career evolution. In this sense, Figure 8 provides some examples of plausible career evolution curves for some extreme behaviors that are discussed in the classroom.

3 PERSONAL AND PROFESSIONAL DEVELOPMENT TOOLS

In general terms, the students find the job environment described so far quite scary. This makes students quite discouraged by the idea that there doesn't seem to be much a young graduate can do to change the formal and informal job performance evaluation procedures they will have to face in the workplace. However, paradoxically to them, the tutor presents this “scary” environment in a very positive way: “*if opportunities for career progress were randomly distributed among the world population, as a kind of lottery, their chances for career progress would be very low”*. Fortunately, the "rules of the game" are fairly predictable and the same for everyone, making those who are better prepared (them!) much more likely to progress. In conclusion, Figure 9 is presented to show that, whereas the knowledge and skills acquired during the academic period open the door to the technology market, to develop a successful professional career, the young graduate must progressively acquire transversal, management and leadership skills. These are divided into two conceptually different groups:

- Instrumental competences. These, with a short-term perspective, are devoted to developing practical capabilities such as communication skills, time management, self-management, proactivity, interpersonal ability and so on.
- Competences based upon principles and values. These are devoted to developing personal growth and character, with a long-term perspective, including features such as identity, authenticity, autonomy, open-mindedness, concern for others, and so on.

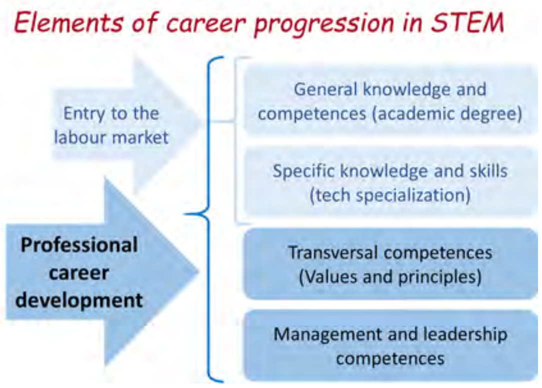

Fig. 9 Elements of career progression.

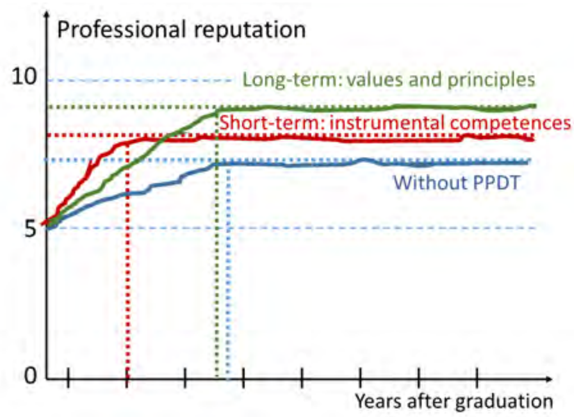

Fig 10. Career evolution models.

The model of work performance assessment discussed in the previous section helps the students to easily grasp the impact of transversal skills and competences on career progression. These PPDT are presented as “experience accelerators”: the acquisition of transversal skills helps the young graduate to achieve a higher professional competence capacity in a shorter period of time (Fig. 10). This figure also shows how instrumental skills can have a fast impact on career progression, but with limited long-term impact. On the other hand, while the development of character traits based on principles and values requires a longer incubation and maturation time, they are expected to produce greater professional competence in the long term. It should be noted that the career evolution curves in Figure 10 simply represent a hypothetical model. Their purpose is to motivate students to seriously undertake career self-management and develop transversal skills. The extent to which students perceive the graphs in Figure 10 as a valuable tool for mapping their career progression determines its effectiveness in fulfilling its motivational objective.

The discussion in the previous section lets us introduce the concept of **“professional reputation”** as what underlies the informal qualification score in Figure 10. It can be defined as the opinion that people, in general, have about someone, or how much respect or admiration someone receives, based on past behaviour, comprising both, technical results and personal relations. STEM graduates, as service providers, sell their competence. They themselves are the product they are selling. This stresses the need to keep improving “the product” by taking good care of their professional reputation. This approach has also shown that makes students more receptive to accepting advice on early-career do's and don'ts [Walesh,1995].

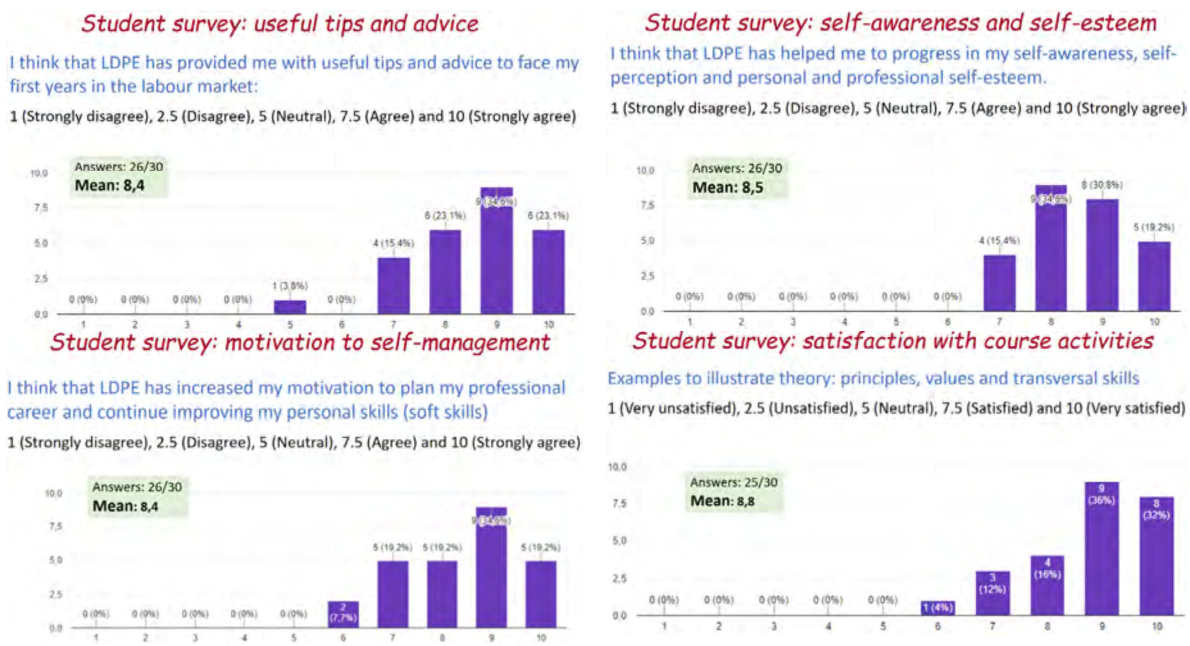

Fig. 11. Some outcomes of a student survey related to the pilot course ***“Leadership and Development of Professional competences in Engineering (LDPE)”***

4 SATISFACTION SURVEY

The result of a satisfaction survey, answered at the end of the pilot course by 26 STEM bachelor students out of a class of 30, is quite encouraging (Fig. 11). Specifically, its three main objectives can be considered fulfilled, as summarized in Table 2.

Table 2 Survey on pilot course objectives

Objective	Mean (over 10)
Provide useful advice for the transition to the labor market	8.4
Increase the motivation of students to plan their professional careers and encourage them to deepen the acquisition of principles, values and transversal competences	8.4
Improve students' self-knowledge and self-esteem	8.5

Table 3 shows student perception regarding the syllabus and the different activities organized within the pilot course. Again 26 students out of a class of 30 have answered the satisfaction survey. As in the previous case, the survey has been conducted by means of a Google form, with anonymous answers, restricted to the list of students in class. It is worth noting the good satisfaction results regarding the selected examples (and their associated class discussions) chosen to illustrate the theory, one of which is the exercise on "work performance evaluation" developed in this paper.

Table 3 Satisfaction survey on pilot course activities

List of topics assessed by the students	Mean (over 10)
Theory: principles, values and transversal competences	8.1
Examples to illustrate the theory	8.8
Debates on real cases (case studies)	8.7
Student presentations and discussions	8.4
Class discussions about specific concepts	8.6
Comments and debates on YouTube videos	8.4

5 SUMMARY AND RESULTS

Acquiring the necessary soft skills and competences to thrive in today's rapidly evolving technology job market often demands years of dedicated effort. Many of these skills can only be fully developed through hands-on experience, real-world projects, and facing practical situations. It is crucial for STEM academic programs to make students aware of this reality and inspire them to take charge of their professional journeys. The experience described in this paper introduces an innovative approach towards achieving this objective, based on the concept of "direction of service". This has been revealed as an outstanding tool to encourage students' self-reflection and the need to self-manage their professional careers. In this context and to illustrate the underlying concepts, this paper has presented a learning and teaching experience held within a pilot elective subject at UPC: "the work performance assessment" as a motivational tool. It employs counterintuitive, paradoxical, or controversial examples to engage students in class discussions This method effectively exposes and reinforces key concepts related to skills and competences essential for career growth, while avoiding preachy or didactic lectures that might elicit resistance from students.

The satisfaction survey performed after the last lecture has shown that students responded positively to this experience, particularly to the exercises (and ensuing debates) chosen to illustrate the theory. It should be noted that this survey also revealed that the three main objectives of this experience can be considered fulfilled: students feel that their self-knowledge, self-esteem and motivation for self-management have been positively reinforced

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TOOLS TO RESHAPE ENGINEERING EDUCATION TO PREPARE STUDENTS AND PROFESSIONALS TO BE GLOBALLY RESPONSIBLE

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ABSTRACT

This paper describes the development of two tools that support educators to prepare the engineers of today and tomorrow for the simultaneous, deeply interconnected challenges that the 2023 Global Risks Report emphasises as a 'polycrisis'. This picture is worsened when considering the Institution of Engineering and Technology

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in 2021 found that only 7% of 1,000 UK engineering companies with a sustainability strategy had the staff with the skills to fulfil it. Against this backdrop, meeting our commitments with integrity, upskilling the current workforce urgently, and ensuring degree courses are future-fit are crucial. In response, these two new actionable tools aid educators in exploring and accelerating curriculum change. First, the Global Responsibility Competency Compass is an articulation of the essential skills, knowledge and mindsets required by the globally responsible practices society needs today. The Compass is designed for everyday professionals in the engineering sector looking to effectively navigate the complexity, uncertainty, and challenges of our age. Second, the Reimagined Degree Map, helps educators develop robust action plans to consider the broader purpose of engineering education and design relevant learning. The Map supports the translation of intention into tangible changes by designing regular learning about engineers' understanding of their global responsibilities and how to navigate through them. This presentation will describe the context and process of the tools' development and present feedback from key stakeholders and early adopters. Early results suggest the tools can support educators in collaboratively embedding sustainability and global responsibility as a core tenet across higher engineering education.

1 INTRODUCTION

University is a formative stage in becoming an engineer. The ability of tomorrow's engineers to enter the workforce as skilled and responsible professionals is shaped by how we educate them today. Universities (and engineering practitioners at all levels) have a huge role to play in prioritising a broader role beyond the traditional focus on technical skills, to ensure engineers can act in a sustainable, ethical and equitable manner; in short - in a globally responsible manner. The recent flourishing of many new and innovative methods, programmes, and institutions attempting to address this reinvention shows that it starts with how engineers are educated (Graham 2018). Scholars now agree that engineering education must respond to and reflect a 'big picture' context, to help learners navigate the complexity and priorities of our age, not just short-term industry needs (Högfeldt et al. 2022). Yet, educators may struggle to find, understand, and/or enact tools within their teaching that enable this change.

1.1 Context

Historically, engineering education has focused on graduates' ability to solve technical problems (Litzinger et al. 2013). While the value of technical skills in an increasingly tech-centric world should not be understated, the narrowing of focus on the technical alone has resulted in the exclusion of critical factors that ultimately interplay with the technical aspects of real-world engineering projects (Munir 2022). In the last decade, engineering educators have been faced with managing and implementing curricular changes, often at a fast pace. One factor has been the emergence of innovative ways to deliver engineering curricula that challenge the traditional lecture-based format of higher education, to deliver skills and project-based learning in response to real-world and industry concerns (Guerra et al. 2017). In addition, the Covid-19 pandemic required a particularly rapid response to switch to virtual learning and alternative assessments (Graham 2022). Faced with these challenges and the impetus to integrate learning for sustainable development, engineering educators may feel stymied about how to enact meaningful change within institutional structures.

People working in all fields are now required to navigate greater complexity and uncertainty in addressing societal and ecological risks. Engineering has to be part of that response, but to effectively do so it must embrace a broader role beyond its traditional focus on technical skills. Further, the sector is therefore being called upon to develop and apply the knowledge, skills and behaviours that reflect the broader impacts that its decisions have on society and the environment. However, when it comes to competency in the UK, there is a risk that an education and skills gap could hinder progress towards decarbonisation, sustainability strategies and net-zero 2050 targets (IET 2021; EngineeringUK 2022). Against this backdrop, educators need to consider what they are preparing tomorrow's engineers for, and why.
To address this challenge, Engineers Without Borders UK (EWB-UK) worked with the Royal Academy of Engineering (RAEng) to conduct a research study in 2019 on the extent to which global responsibility is embedded in engineering practice (Engineers Without Borders UK 2022). The findings from this study spurred an action in 2022, to spark wider change to reimagine what a globally responsible degree would look like and consist of. This work would build from the efforts EWB-UK has been undertaking to upskill over 250,000 people by 2030 with the skills and expertise to be globally responsible, highlighting the need to reimagine existing competency frameworks. This approach guided the development of tools that engineering educators can employ to equip future and current engineers with the skills required to respond effectively to the challenges of our age.

2 METHODOLOGY

2.1 Defining the skills gap

First, it was necessary to understand and define what knowledge, skills, and mindsets engineering students require in the area of global responsibility. To do so, we drew upon the four guiding principles for the teaching and practice of engineering that were established through the development of the EWB-UK strategy for 2021-2030 to put global responsibility at the heart of engineering: **Responsible** (To meet the needs of all people within the limits of our planet. This should be at the heart of engineering), **Purposeful** (To shape outcomes to be equitable and ethical throughout engineering and the life cycle of any project), **Inclusive** (To ensure that diverse viewpoints and knowledge are included and respected in the engineering process and outcomes) and **Regenerative** (To maximise the ability of all living systems, to achieve and maintain a healthier state and naturally co-evolve).
Initial proposals of related competencies under each principle were framed under knowledge, skills and mindsets to align with theories suggesting that learners must both acquire and integrate these three areas to achieve competence (Baartman and de Bruijn 2011). Research was then undertaken into existing competency frameworks and literature to understand how these principles are presented internationally and in the UK, to support embedding these principles into day-to-day engineering practice. This process revealed the large number of existing competency frameworks that help professionals focus on specific areas of training, build workforce capability and identify skills gaps, or make a determination about professional qualifications. With this in mind, the goal became not to replace these existing frameworks, but to enhance them and support the lifelong learning required from engineering professionals with the competencies of global responsibility. What emerged was the Global Responsibility Competency Compass as an articulation of the essential skills, knowledge and mindsets required to embed global responsibility

in engineering approaches and outcomes (which can be downloaded at www.ewb-uk.org/global-responsibility-competency-compass). The Compass sets out 12 competencies and is organised around the four guiding principles of global responsibility.

2.2 Keeping curriculum relevant

The Compass is focused on the competencies required of multidisciplinary groups of professionals that work in engineering. These competencies must also be enabled through the education and training of these professionals, which in turn requires a change in higher engineering education (Högfeldt et al. 2022). Therefore, in response to the challenges inherent in supporting that change, the Reimagined Degree Map was developed to help guide curricular adaptation by shifting the focus on areas such as sustainability and global responsibility from being ad hoc and optional, to being of high quality and being a core thread across the education of engineers. Studies have shown that this is in demand by students, with 60% expressing they would like to learn more about areas such as sustainability (Students Organising for Sustainability 2021). Doing so will require “a more thoughtful approach that encompasses the social, human, economic and environmental impacts of engineering" and “more complexity in the curriculum” (UNESCO 2021, 123). However, making changes to curriculum also takes time, effort and motivation. The Map pulls from the experience of EWB-UK, the RAEng, expert educators, and a knowledge bank of research. It is rooted in a strong vision to integrate education that enables graduates to develop their ability to act sustainably, ethically and equitably throughout their careers. It is also action-oriented so that universities can make these changes practically and quickly. The Map is framed around a series of exercises to aid educators, deans and heads of departments to make changes to create, share and explore empathetic, impactful and relevant changes to engineering curriculum, including:

1. Bringing together teams across faculty, school or engineering departments in creative collaborations to build a shared understanding of the current state of engineering education at their institution, and build teams' confidence in critical conversations with students about the future of engineering.
2. Exploring the broader context for today's educational system (the complexity, uncertainty and challenges of our age), to keep curriculum relevant and translating what this means for civil, mechanical, electrical, general and chemical higher education engineering courses.
3. Identifying interventions educators can make to curriculum (such as adapting learning outcomes, active pedagogies/techniques to deliver complexity, real-world project briefs and mindset development, maximising multi-disciplinary experiences, and authentic assessments), to design relevant learning for students to understand and embrace their broader responsibilities as a core thread of their learning experience.

In unpacking the complexity of holistic student learning journeys, the Compass and models such as Doughnut Economics (Raworth 2017) and the UN’s Sustainable Development Goals, helped guide initial ideation by providing a framing of the global context and professional development needs emerging engineers will be entering into. The Map is also rooted in well-versed models for building learning, mindsets and approaches over time, including: Bloom’s taxonomy of learning, Bill Lucas’s habits of mind (Lucas and Hanson 2014), Maslow’s hierarchy of needs (Maslow

1943), and Kohlberg and Rest's theories of moral development (Rest et al. 2000). Sustainability components can link to competencies required by accrediting or professional organisations (e.g. AHEP 4, GAPC, UK-SPEC), while linking to other curriculum maps for different engineering disciplines, meaning educators can see an example of how the sustainability components can link to learning outcomes in particular modules.

3 DISCUSSION

3.1 Consultations

To test the approaches and content articulated in the Map and the Compass, a series of consultations and testing with educators, students and professionals in the sector was undertaken. These were conducted through events, conferences and workshops with participants via surveys using Menti (www.menti.com) to gather feedback. These consultations were undertaken in the context of the Accreditation of Higher Education Programmes (AHEP), which in the UK aligns with the Engineering Council's Standard for Professional Engineering Competence (UK-SPEC) for professionals' competence and commitment. During the consultation phase of the Compass development, the Engineering Council endorsed it "as a useful resource that complements the requirements of UK-SPEC. This tool helps to bring to life and articulate the skills and actions everyday engineering professionals need to act in a way that is sustainable, equitable and ethical" (Engineering Council 2023). AHEP is intended to be read in the context of the competence and commitment required for professional qualifications (Engineering Council 2020). Participants during consultations were asked to reflect on their vision for the future of higher engineering education. An example of the responses is presented in Figure 1.

Fig. 1. In one word, what is your vision for engineering education (educators at the Institution of Structural Engineers, n=23).

Ideas related to sustainability, regenerative practices and the inclusivity of approaches came out as top themes for the future vision of higher engineering education, with similar responses from other engagements. When students were asked what they thought was an engineer's most valuable attributes, the responses were ranked in the order as: problem solver, socially aware, environmentally aware, collaborative, technical and interpersonal. However, participants' reflections on their own education suggested that sustainability was not a core part of their higher education, and is not so for current students (Figure 2).

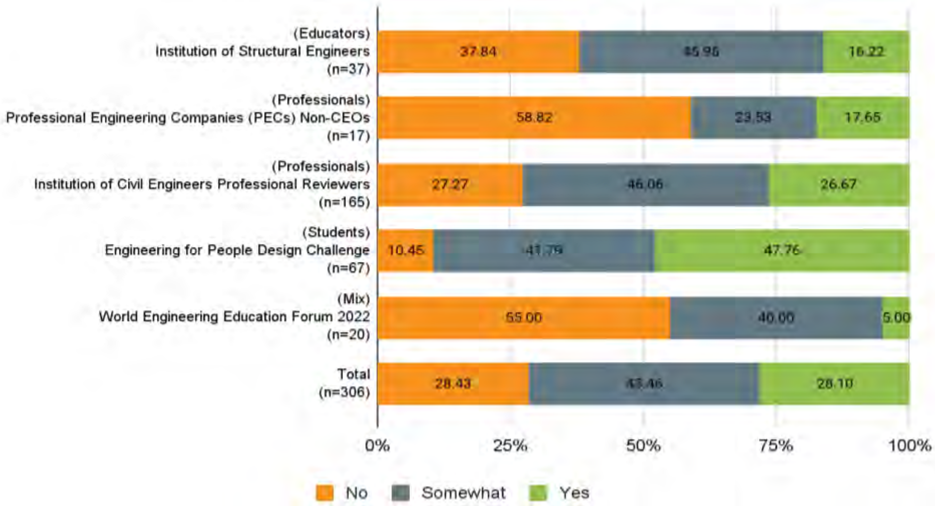

Fig. 2. In your opinion, did your degree, or equivalent, prepare you to act sustainably and equitably? (Note: Students at first and second-year undergraduate reflect on their degree currently. The [Engineering for People Design Challenge] is a real-world in-curriculum design challenge delivered through project-based learning, to broaden awareness of the social, environmental, economic, and ethical implications of engineering alongside technical skills).

Across professionals and educators, less than a third reflected that sustainability was core to their education. Less than half of students reflected that sustainability is core to their current education, complementing previous studies that this is in demand from students (Students Organising for Sustainability 2021). Nearly 72% of total participants said sustainability either “is not” or “is somewhat” included in their higher education. There is a consistent vision of embedding sustainability and global responsibility into how higher education is taught (Figure 1) and recognition that higher engineering education has yet to embed it as a core tenet (Figure 2). Participants - both practitioners and educators - also expressed notable importance and willingness attached to changing how engineering is taught and practised (Figure 3). However, there is a confidence gap in understanding how to do so.

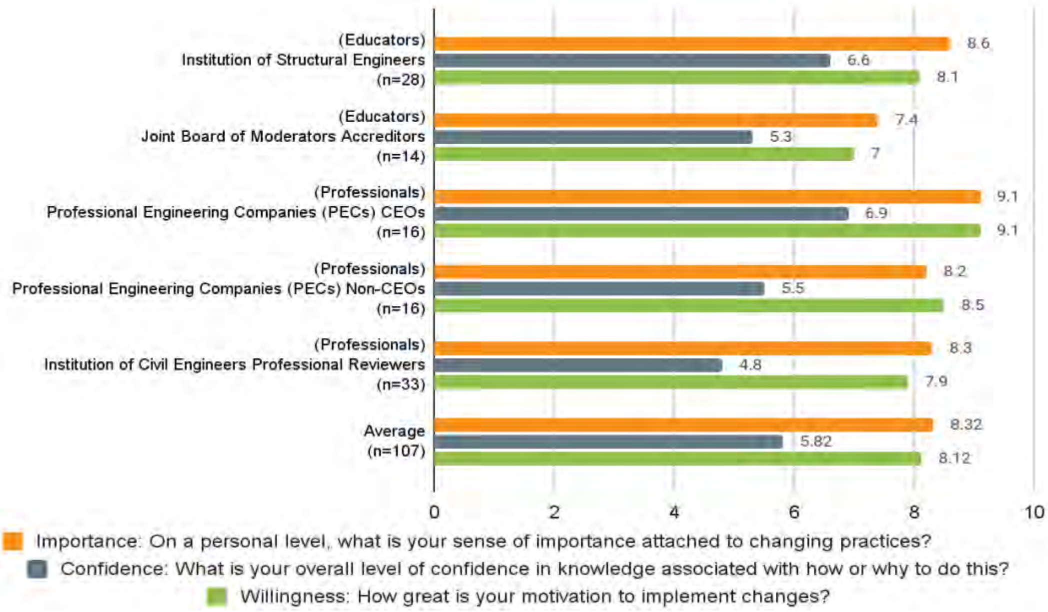

Fig. 3. Movement towards changing practice to embed global responsibility. (Note: Joint Board of Moderators asked through the context of the Climate Emergency).

During engagements, educators cited the top barriers to ensuring teaching focuses on global responsibility:

- The pace of change needed and the stress this places on individuals.
- Hesitance in managing the change well with the time available while keeping accreditation and improving student satisfaction.
- Access to globally relevant (and up-to-date/diverse) expertise to support teaching about sustainability that is motivational to students.

For educators looking to keep curriculum and learning outcomes relevant, the Compass provides a useful framing to inform learning outcomes throughout the curriculum. It encourages lifelong learning for emerging engineers and supports the reskilling of engineering professionals (to pursue topics that may have been absent from the individual's formal education) and constant evolution in competency through educational activities. Across all engagements, there was a key focus on competencies related to critical thinking, awareness, navigating complexity, resilience, empathy, collaboration and inclusion, and identifying solutions. Participants also recognised that knowledge and skills are a strong focus in higher engineering education, while mindset development, reflected in the Compass, is more challenging to reflect in the current curriculum. However, early feedback on the Map suggests that starting with exploring the broader context and what mindsets students are developing was helpful framing while showing how it can be incorporated into existing areas of accreditation and signposting to best practice. Additional feedback also indicated that the Map could be effective in collaboration and communication with professional engineering institutions and other university departments - with the aim of bringing all engineering courses together for a minimum standard of delivery that is directly relevant to industry and society.

3.2 Limitations and future work

The development of the Compass and the Map has been informed by research incorporating insights internationally and in the UK. However, for practical reasons, the consultations and testing with the educators, students and professionals presented in this paper were limited to the geographical association of the authors (except for the World Engineering Education Forum and Institution of Civil Engineering Professional Reviewers). Expanding on how these tools are received globally can be expected as these tools develop and roll out. Future work will include sharing relevant learning within a global community of educators and practitioners and critically reflecting on how to continuously evolve what globally responsible engineering looks like. Longer term, it will be important to tilt towards greater geographic diversity in capturing lessons learnt and gaining wider perspectives to inform research and advocacy efforts in the global educational systems. In particular, this should include engagement with more educators in emerging economies where there are large numbers of engineering graduates (or where capacity is growing in the future).

The exercises in the Map aim to identify creative collaborations that can deliver high-quality learning, to bring in wider expertise, from different departments, faculties and industry, and focus the time spent by educators more effectively. It is not incumbent on individual educators to create all learning content and deliver it to students. For example, the Engineering for People Design Challenge provides evidence of higher engineering education working with organisations to embed relevant and complex contexts in engineering curricula. The RAEng and EWB-UK are bringing together a group of early adopters made up of higher engineering educators to test the Map, and a community of contributors for both tools to support their delivery and adoption while building knowledge on how they are used to accelerate change.

4 SUMMARY

While the Map and Compass are separate tools, they are complementary and are intended to inform each other in designing holistic learning journeys from higher education to professional life with global responsibility as a core thread. Both are aimed at giving users greater agency.

Engineers do not work only with engineers and must work in deep collaboration with other disciplines, foster active participation from citizens in decision-making, and adopt holistic approaches. The positioning of the Compass is purposefully not exclusive to engineers; it values the multi- and interdisciplinary contribution of non-technical skills and also challenges the value that engineering typically places on the dominance of narrow competencies. In turn, the Map encourages collaboration to prepare emerging engineers in the multidisciplinary delivery of real-world projects, within the curriculum. The outcomes of the early adopter engagement will be shared during the conference.

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Engineering Faculty & Staff Inclusive Excellence Training: Broadening Engineering Pedagogy for All

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ABSTRACT

As our classrooms become more and more diverse, the need for cultural competency in engineering faculty is more important than ever. Cross-cultural competency has been named among the 10 most important skills for the future workforce. Historically there is a lack of cultural diversity at East Tennessee State University. The university did not offer any formal training opportunity for faculty and staff in cultural competency. As such, faculty effort in cultural pedagogy is minimal resulting in persistent achievement gaps among culturally diverse students. In this project we have developed and implemented an inclusive excellence cultural competency training program primarily for engineering faculty and staff primarily in the College of Business and Technology. The project aimed to train these faculty and staff in cultural competency so that they can implement inclusive pedagogy and communication in and out of their classrooms. Cross-Cultural Adaptability Inventory and post workshop assessment were used to measure the efficacy of the training program. Assessment data showed that the training program improved faculty and staff's awareness in wide variety areas of cultural proficiency and provided them with a toolbox of ideas to implement them in their classes and workplaces. Lessons learned are: 1) To make an institution a culturally inclusive institution diversity, equity and inclusion need to be part of the organization DNA and leadership buy-in and advocacy is a must; 2) Whenever possible, create developmental approaches that engage faculty and staff with different levels of content over a period of time and 3) Provide flexibility in training delivery.

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1 INTRODUCTION

Cultural competence is the ability of a person to effectively interact, work, and develop meaningful relationships with people of various cultural backgrounds (Durden, et al. 2016). Cross-cultural competency has been named among the 10 most important skills for the future workforce (Fidler and Gorbis 2020). Employers value culturally competent employees in designing, developing and marketing their products and services to culturally diverse customers (Swayze and Calvin. 2016; Bhawuk 2009; Palmer and Carter 2014). Cross-cultural competency is the key enabling factor of working in diverse teams (Alexis, et al. 2017; Lokkesmoe, et al. 2016; Trooboff, et al. 2008). Furthermore, there is also need to utilize the talents, experiences, and ideas of a broad group of people in order to achieve inclusive excellence and student success. As our classrooms become more and more diverse, the need for cultural competency in faculty is more important than ever (Burns 2020; Ekaterina, et al. 2015; Frawley, et al. 2020).

East Tennessee State University (ETSU) is committed to diversity and inclusion and has aspired to become a campus enriched by persons of different backgrounds, view, cultures, socioeconomic statuses, and other characteristics by infusing inclusion into all aspects of university life. However, there is a lack of diversity at ETSU. Only 10.89% faculty are non-white compared to 19.26% minority race/ethnic students and this disparity is increasing (ETSU Fact Book 2020). The majority of faculty and staff at ETSU hail from a middle-class, European-American background; therefore, the biggest obstacles to successful culturally responsive instruction for most faculty are disposing of their own cultural biases and learning about the backgrounds of the students that they will be teaching. European-American culture simply dominates social and behavioral norms and policies to such an extent that those who grow up immersed in it can be entirely unaware of the realities of other cultures. A related misconception that many faculty labor under is that they act in a race-blind fashion; however, most faculty greatly overestimate their knowledge about other cultures, which manifests itself in a lack of cultural sensitivity in classroom management and pedagogical techniques (Freedman, et al. 2003). A faculty member’s lack of understanding of diverse cultures and beliefs can lead to disparities in learning, dissatisfaction, and achievement gaps among diverse students (Embrick, et al. 2018). On the other hand, a culturally competent faculty member can establish trust and respect, improve levels of communication, and create an inclusive learning environment. This project has two major goals: 1) Train the faculty and staff primarily in the College of Business and Technology in cultural competencies and enable them to understand, communicate and effectively interact with people across different cultures and 2) Develop a sustainable cultural competency framework for faculty and staff to be used by other colleges and departments.

2 METHOD - TRAINING PROGRAM DEVELOPMENT AND IMPLEMENTATION

To equip the faculty and staff in the College of Business and Technology at ETSU in cultural knowledge and adapting to diversity, this project implemented the “Train the

Trainer" Model, is a widely acknowledged educational model across a number of disciplines (Pearce, et al. 2012; Tonna and Bugeja 2018). The train the trainer model was selected because it has a self-sustaining mechanism and provides an effective strategy to equip faculty and staff with new knowledge on how to teach others and how to foster an environment where everybody feels welcome to improve their skills. A train the trainer workshop can build a pool of competent faculty who can then teach the material to other faculty members. Instead of having just one trainer who trains/teaches a course, there are multiple trainers training/teaching the same course at the same time in this model. This means a new participant typically gets to watch an experienced trainer teach, complete the exercises, and then practice teaching segments to other participants.

We recruited a nationally renowned trainer, Dr. Yvette M. Alex-Assensoh, Vice President for Equity and Inclusion at the University of Oregon, to develop a training program on inclusive excellence through cultural competency for the College of Business and Technology faculty and staff. Dr. Yvette M. Alex-Assensoh is an award-winning researcher, university professor, and equity strategist as well as a member of the Oregon and Indiana State Bar Associations, Leadership Consultant, Certified Coach, Workshop Facilitator and Keynote Speaker. She has, over the last 25 years, delivered results in higher education, with non-profits and faith-based organizations as well as for individuals across America, and in Africa, Asia and Europe. Her life-long belief in the power of unconditional love, as actualized in L.A.C.E., is the driving force behind how she conducts research, teaches, leads and coaches (Alex-Assensoh 2020).

Dr. Alex-Assensoh, the authors and the ETSU Office of Equity and Inclusion collaborated to create a training workshop for faculty and staff with the following learning outcomes (Goal 1). The faculty and staff will be able to:

(i) demonstrate a solid understanding of cultural diversity in classroom teaching;

(ii) effectively accommodate diverse students through inclusive pedagogy and intercultural communication;

(iii) effectively prepare students for careers with cultural knowledge and diversity skills.

Two assessment tools were also developed to measure the project success. The workshop was administered over four Fridays via Zoom due to COVID restrictions. Each session ranged from 2 to 3 hours with total ten contact hours. Each session consists of a pre-workshop reading assignment, in-session presentation, group discussion and hands-on activities. The faculty and staff enjoyed each session so much that after each session many of them stuck around to continue their group activities or chat with Dr. Alex-Assensoh. This demonstrated faculty and staff's enthusiasm to learn about cultural inclusiveness and commitment to make ETSU a place of cultural pluralism to enhance the success of students of every race and nationality. Additionally, a total of 15 grants were awarded to faculty to apply the learning of the workshop into their classes to train students in cultural competency.

In Spring of the following year, four newly trained faculty and staff assumed the trainer role and trained a new group of faculty and staff. Due to high demand, the workshop was administered to two cohorts of faculty and staff. There were 21 participants in each cohort. We recruited one faculty and one staff from each cohort who completed the Fall workshop to lead the Spring cohorts. Both faculty and staff leads worked together early in the spring semester and built the workshop on ETSU's D2L learning management system. The participating faculty and staff were enrolled as students in the D2L system and the workshops were administered over four Fridays similar to the Fall workshop and assessment data was collected. After Spring implementation, the training materials were handed over to the ETSU Office of Diversity and Inclusion for wider deployment of the training to all colleges and offices (Goal 2). It is anticipated that over the time the cultural awareness and inclusive pedagogy will be an integral policy and practice in all aspects of ETSU.

3 RESULTS

ETSU Inclusive Excellence through Cultural Competency Workshop was a huge success. Our primary target population was engineering faculty and staff from the College of Business and Technology, but due to high demand we made it available to other colleges. A total of 42 faculty and 22 staff completed the workshop representing eight colleges of ETSU and three offices (Figure 1). By expanding it to other colleges, we achieved broader participation and impact. Trained faculty and staff members are now equipped and motivated to infuse cultural pedagogy in their classes and workspaces to make ETSU a more inclusive campus.

3.1 Participants' Demographics

Of the 64 faculty and staff who completed the workshop 78% self-identified as female, 17% as male, and 5% as other gender. The ethnicity/race distribution of the participants was: 79.6% White, 11.1% African American, 5.6% Asian and the rest are in some other ethnicity. As expected, the educational background of the participants skewed to the left: 9.3% had a Bachelor's degree, 20.4% had a Master's degree and 63% had a doctoral degree.

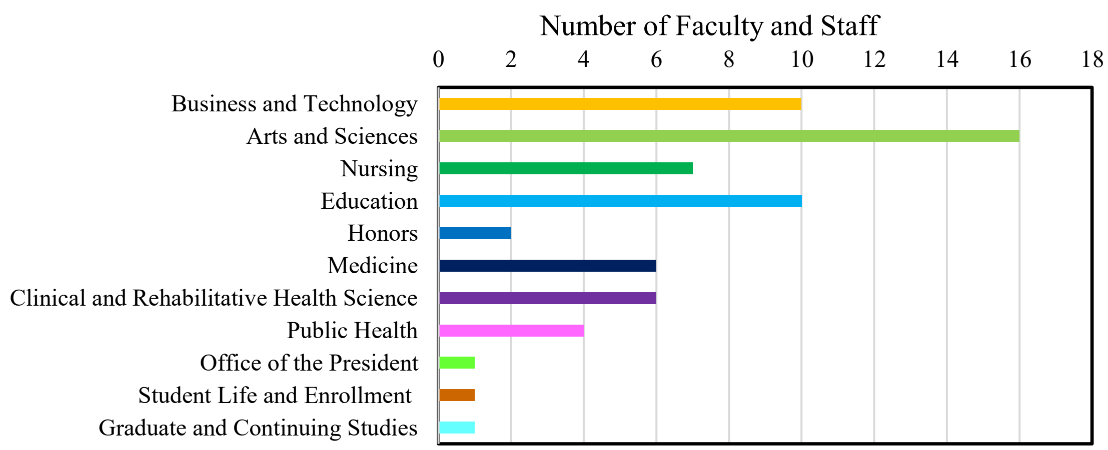

Fig. 1. Number of Participating Faculty and Colleges

3.2 Assessment

During the Fall and Spring workshops we collected two sets of data to assess the effectiveness of the workshop and how it has prepared faculty and staff by improving their awareness about identity, implicit bias and cultural proficiency. The assessment tools used were 1) Cross-Cultural Adaptability Inventory and 2) Pre and Post Workshop Assessment

I. **Cross-Cultural Adaptability Inventory (CCAI)**: This inventory was developed by Colleen Kelley and Judith Meyers as a self-assessment tool that prompts multi- cultural discussions and help employees work successfully within a culturally diverse environment (Meyers and Kelley 2015). The CCAI measures four distinct areas of cultural competence with high statistical reliability and face, content, and construct validity. Published research also shows increasing evidence of predictive validity.
The four CCAI dimensions are:

- Emotional Resilience: Measures how one balances emotions, navigates difficult feelings, and maintains a positive outlook.
- Flexibility/Openness: Indicates how nonjudgmental and tolerant one can be towards new ideas and customs. This also measures how much a person enjoys encountering different ways of thinking and behaving.
- Perceptual Acuity: Measures how effective an individual is at discerning the subtle verbal and nonverbal cues in a cultural environment. Perceptual acuity encompasses attention to detail, sensitivity to the feelings of others, and general awareness of nuanced interpersonal context.
- Personal Autonomy: Indicates how dependent one is on familiar cultural cues to form an identity. This dimension shows how strongly one retains his or her sense of self and values in any environment or culture.

We administered the CCAI pre and post workshop. Typically, the CCAI scores are plotted on a radial diagram as a self-assessment profile. The score that is closest to the outer edge of the profile indicates one’s strongest area, and the score that is closest to the center of the profile indicates one’s weakest area. For simplicity a comparative bar chart is created which shows that after attending the workshop participants’ scores increased in all four areas; however, they are not statistically significant except for emotional resilience dimension which is statistically significant at 5% significance level (Figure 2).

The range of scores for **emotional resilience** can vary from 0 to 108. Being among people from another culture can be frustrating, confusing, and lonely. In these situations, it is important to be able to maintain a positive attitude, to tolerate strong emotions, and to cope with ambiguity and stress. It is also helpful to be able to maintain one's self-esteem and self-confidence. The post workshop score of 88 compared to 79 in pre-workshop indicates that the workshop helped faculty and staff to improve their ability to cope with the unfamiliar cultures and to react positively to new experiences. This demonstrates courage, risk taking, and a sense of adventure among the participants.

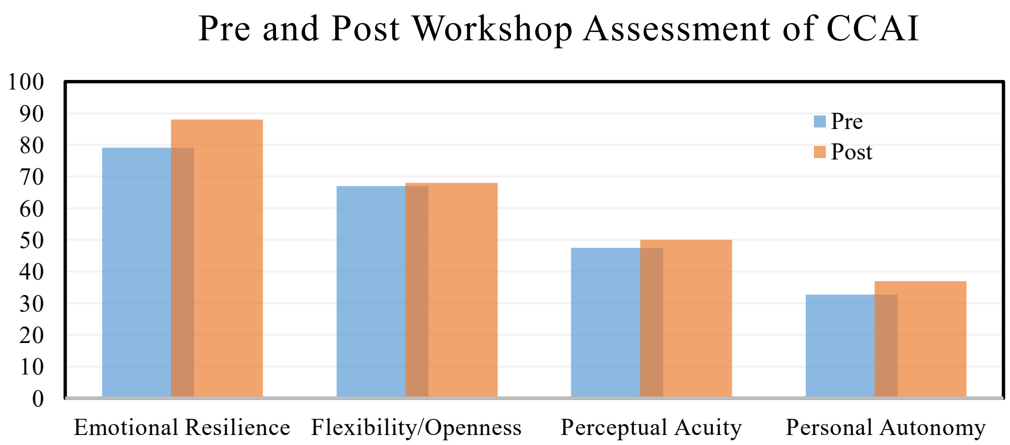

Fig. 2. Pre and Post Workshop CCAI Assessment

Flexibility/Openness scores can vary from 0 to 90. Adapting to different ways of thinking and acting requires an ability to be open to ideas that are different from one's own and to people who are different from oneself. These characteristics are also helpful in developing relationships with people who are different from oneself. The pre and post workshop scores (67 vs 68) show average openness of our participants toward differentiating ideas, tolerance, and a of liking for and comfort with people with diverse background. As there is significant room for improvement in this dimension, ETSU needs to implement reinforcing activities to improve the flexibility and openness of our faculty and staff.

Perceptual Acuity scores range from 0 to 60. Unfamiliar language-verbal or nonverbal-makes communication more difficult. Perceptual sensitivity is the key to successfully meeting this challenge. Perceptual acuity is associated with attentiveness to interpersonal relations and to verbal and nonverbal behavior. The post workshop score of 50 shows that the faculty and staff demonstrated above average percentual acuity. They are able to understand people's emotions in diverse situations and cultures, pay attention to the context of the communication, being sensitive to one's effect on others, and communicating accurately.

The scores for **Personal Autonomy** range from 0 to 42. When one encounters people whose values and beliefs are different from one's own, self-knowledge is important. The main characteristic associated with personal autonomy is a strong sense of identity. Personal autonomy also includes the ability to maintain one's own personal values and beliefs, to take responsibility for one's actions, and to respect oneself and others. Post workshop score of 37 (vs 33) shows that the workshop helped the faculty and staff improved their sense of personal autonomy. They feel empowered to make ETSU more inclusive and equitable to all cultures. They know how to make and act on their own decisions while respecting the decisions of others.

II. **Post Workshop Assessment**: A post workshop assessment tool was developed and administered after the workshop. Participants were asked to rate statements focusing on learning outcomes on 1 to 5 Likert scale (1: Strongly Disagree, 3: Neutral and 5: Strongly Agree). The survey had 15 questions focusing on several areas. 1) Identity: having an awareness of the participant's own identify, identity of others, how identities are correlated with equity, power and difference and strategies and activities to help students to develop their identities which are associated with increased self-esteem, improved mental health, and greater academic achievement. 2) Recognition of implicit bias: understanding of implicit bias and the role that it plays in perpetuating stereotypes and discrimination, understanding colorblindness and how colorblind ideology ignores patterns of discrimination, and strategies to mitigate the involuntary and unconscious associations that produce bias. 3) Cultural competency: creating learning and/or working environments in which students, faculty and staff feel respected by and connected to one another; helping students, faculty and staff at ETSU to be more culturally proficient and to incorporate the proficiency into my daily job duties. 4) L.A.C.E. Framework: understating L.A.C.E. and how to use it to raise self-awareness in work at ETSU. And 5) Support: understanding of how to partner with the ETSU Office of Equity and Inclusion to ensure that equity and inclusion are core values and outcomes in my campus unit. Assessment data shows that in their opinion the workshop has improved faculty and staff's awareness in wide variety areas of cultural proficiency and provided them with tools and processes to implement them in their classes and workplaces (Figure 3).

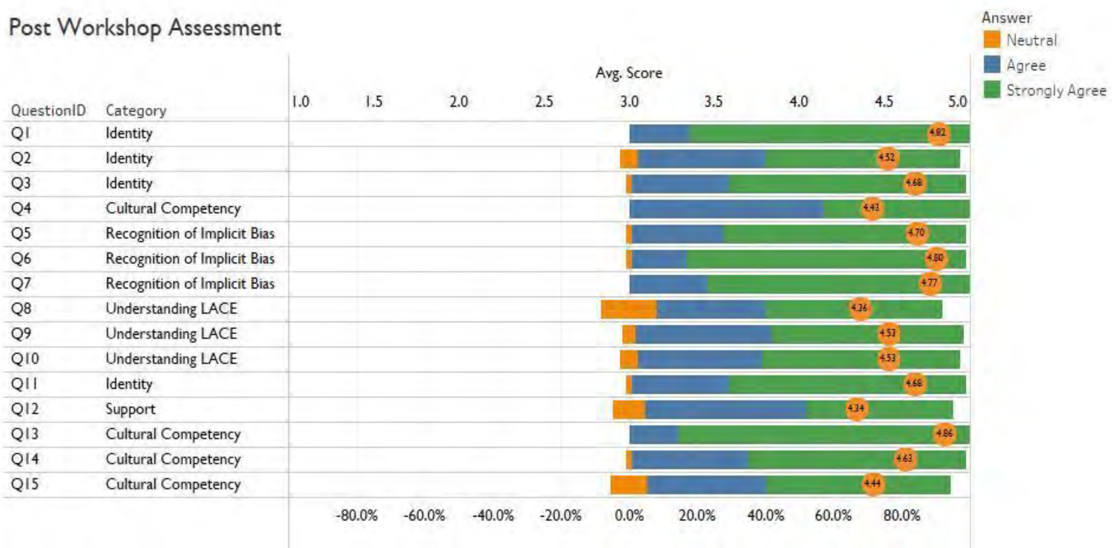

Fig. 3. Post Workshop Assessment

4 LESSONS LEARNED AND RECOMMENDATION

In the landscape of today's global economy, industry and government organizations can expect to have employees and clients from numerous cultural backgrounds and varied cultural practices, needs, and expectations. As a result, businesses worldwide are looking for ways to bolster relationships across cultural lines. Knowing how culture impacts management style, problem-solving, asking for help, etc., can help us communicate better in cross-cultural interactions. As educators, we need to prepare our students with cultural skills and knowledge and bring awareness to stereotyping and prejudices that can create barriers in the workplace. For those on other campuses working to organize such workshops, we have following recommendations:

1. *To make an institution a culturally inclusive institution Diversity, Equity and Inclusion need to be part of the organization DNA and leadership buy-in and advocacy is a must*. At ETSU, faculty and staff understand changing demographics and cultures in their classrooms and workplaces, and they are willing to learn and adjust to accommodate culturally diverse students. It is the support of faculty and staff (as opposed to being resistant) has made this project successful and paved the way to make ETSU a more inclusive institution for students' success.
2. *Avoid one-offs when possible*. In this new age of increased attention to racial justice and diversity, it may be tempting to offer lone workshops to satisfy a diversity checklist. But while well intentioned, singular or isolated sessions have the unintended consequence of leaving faculty and staff frustrated with more questions than direction. Whenever possible, create developmental approaches that engage participants with different levels of content over a period of time.
3. *Provide flexibility in workshop delivery*. We administered the workshop over four weeks in pieces and via Zoom and it provided flexibility and convenience for the faculty and staff. We also had many small and interactive group discussions during the workshop which helped participants to open up about personal experiences around identity, socialization and implicit biases. Helping others to walk in someone else's shoes can be transformative, especially when we're asking them to unlearn years of socialized bias.

5 CONCLUSION

ETSU is committed to diversity, equity, and inclusive excellence both locally and globally. ETSU's inclusive excellence training program has provided faculty and staff with skills and tools to create classroom climates that are respectful and inclusive and that help students' value and understand the cultures of their peers. This will increase student engagement in collaboration, experiential learning and equtable opportunities for success. The train the trainer model will help expand the program in other units of the university. Trained faculty and staff will be able to create an inclusive classroom in which all students have equal access to information, regardless of sociocultural background. Bringing in diverse perspectives about content, creating opportunities for students to share their background and experiences, and limiting culturally biased curriculum are great ways to create a more inclusive classroom. This sense of belonging will contribute to CBAT student retention and persistence to graduation. When the college focuses on preparing students to understand the overall function, awareness and effectiveness of cultural competency, they will be providing students with the necessary skills needed to function in the ever changing local, national and global workforce.

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EDUCATING FUTURE ROBOTICS ENGINEERS IN MULTIDISCIPLINARY APPROACHES IN ROBOT SOFTWARE DESIGN

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ABSTRACT

In 2020, a new two-year MSc programme in robotics was launched. Unlike most existing robotics programmes, which approach robotics from a specific discipline, this programme aims to train multi-deployable robot generalists using a cognitive approach (no hardware creation). The field of robotics is multidisciplinary by nature and educating students on how to approach projects with a multidisciplinary mindset is at the forefront of the programme. Hence, at the end of the first year, students are thrust into experiencing the true multi-disciplinarity of the robotics field in a synthesizing, multidisciplinary project-based course. In this 5 EC course, students work together in groups of 5 on an industry-based assignment making a translation of societal issues from different perspectives (human, sustainability, safety, ethics,

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economic, etc.) into intelligent robot solutions. Each team develops and tests a complete, integrated software package for a complex robot system in a simulated environment and implements it in a real robot at the end of the course. Various robots are used, each related to a different case study which is taken on by multiple teams. Students are supported in their project with workshops and minilectures on transferable skills, systems engineering and the Robot Operating System (ROS). This paper describes the development, implementation, and results of the course over its first three years of running. It will present lessons learned from the perspectives of all parties involved: lecturers, technical staff, industry, and students as well as future plans and recommendations for others looking at creating similar courses.

1 INTRODUCTION

The field of robotics, like other discipline-focused fields such as aerospace engineering and maritime architecture, is multi-disciplinary in nature. This is why in 2020 a new multi-disciplinary 2-year MSc degree in Robotics was set up at Delft University of Technology in the Netherlands. The MSc Robotics was developed together with students and industry, to ensure the relevance of this programme. It was first run in the academic year 2020-2021. Its focus is on educating future robot software engineers, who are comfortable in a variety of mechanical engineering and computer science disciplines including machine perception, artificial intelligence, robot planning and control, human-machine systems, and ethics. The robotics engineer is trained to be creative and to find solutions from different perspectives. As such, it is crucial for robotics engineers to receive education not only in a diverse array of purely technical disciplines but also in human-robot interaction as well as societal and ethical aspects.

The approach to training these robotics engineers is to guide them through several mandatory courses which are connected to the previously mentioned disciplines. In addition, a course called Vision and Reflection runs in the first 2 quarters of the first year, integrated into the other courses. To achieve the aim of becoming a Reflective Engineer (Hermsen et al 2022), reflection forms a key part of the programme. In this course, students discuss their experiences and future plans in terms of electives and skills development under the supervision of both a PhD candidate and an older student. More details on the entire MSc Robotics programme can be found in Saunders-Smits et al. (2023).

The RO47007 Multidisciplinary project is the last mandatory course in the first year of this new Master's programme. The aim of the project is to let the students work on a problem currently relevant to the robotics industry, while they practise and combine the knowledge they have found in the previous courses. They receive aid and feedback about how to run such a project in terms of communication and project management. This 5 EC course forms the synthesizing capstone project at the end of the first year before the students transition to the second year in engage in individual and diverse group work, using provided tools and methods while devising novel theories or design techniques to address intricate mechanical engineering challenges. In this paper, we will detail the course setup and the didactical concepts behind the course design, share our initial experiences, and report on a small study of student experiences in this year's run of the course.

2 COURSE DESIGN

2.1 Learning Objectives

The learning objectives for this course are divided into two domains: Knowledge, Insight, Judgment and Skills, and Transferable and Interpersonal skills. In the Knowledge, Insight, and Judgement & Skills domain, students should, by the end of the course, be able to:

- Define a problem definition and its corresponding requirements.
- Design relevant (robot) solutions in the field of robotics by integrating knowledge on opportunities, trends, and societal aspects.
- Design relevant (robot) solutions in the field of robotics by integrating knowledge on opportunities, trends, and societal aspects.
- Use functional architecture for planning and communicating robot software.
- Communicate the multidisciplinary robot solution in a clear way, both orally, in writing, and in code documentation.

In the Transferable and Interpersonal skills domain, students should, by the end of the course, be able to:

- Formulate and adjust learning goals on personal development
- Reflect on one's own competencies (e.g., Teamwork, Leadership, Entrepreneurial thinking, Strategic multidisciplinary problem solving) and development in these and determine where personal learning goals and interests lie;
- Show to use feedback to improve one's own performance or performance of others;
- Apply structured multidisciplinary software project management, with the use of different team roles and responsibilities

2.2 Course Set Up

In this 8-week course, students work in groups of 4-5, on an industry-based assignment making a translation of societal issues from different perspectives (human, sustainability, safety, ethics, economics, etc.) into intelligent robot solutions. Each team develops and tests a complete, integrated software package for a complex robot system in a simulated environment and tests this using a real robot at the end of the course. Since the second edition of the course, 4 robotics companies, research institutes or innovation centres supply students with a relevant challenge they face in their own robot development which they would like the students to provide solutions for. Each group of students consists of 5 so-called specialists, who are responsible for a specific part of the software design and implementation. The specializations used are *human-robot interaction, navigation, planning, perception,* and *motion control,* and relate to the different disciplines within robotics. In addition, students are also asked to choose other additional project management-based roles and their natural roles (such as team leader, etc.). They are asked to reflect on these roles as part of the continuous reflection within the course as a natural follow-up on the Vision and Reflection course. To mimic the project management styles used in the robotics industry the course planning is divided into 4 sprints to allow students to experience an Agile working approach. At the end of each sprint, a version of a living report should be handed in. Students receive feedback shortly after.

Students are supported in their project with workshops and minilectures on transferable skills, project management, systems engineering, and a refresher of the Robot Operating System (ROS) in which they were previously trained. These take place in the first 5 weeks of the project and are offered on a deliberate just-in-time basis. The client interaction in the course starts off with a company visit on the second day of the project, in week 4 students present their initial proposed design to their client for feedback and present their final design at the end of week 8. During this final presentation, students present a demonstration video of the robot executing their solution to the client’s problem.

2.3 Robot design approach in the course

The Robotics master programme is very much focused on cognitive robotics and not on designing physical robots. Therefore, this project has been developed along this philosophy, in line with what most students will incur in industry once they graduate. They are expected to work with the robots and manipulators the company uses. All student groups work with simulations of a robot using ROS until they can test their software on the real-life version of their robot in weeks 5-7 of the course. In the 2022-2023 edition of the course, 4 different robots are used that are all available to students in-house: A Clearpath Robotics Boxer with a Panda arm to be deployed in supermarkets, a Boston Dynamics Spot (including arm) to look at the feasibility to employ it in object retrieval, a Clearpath Robotics Ridgeback with a Doosan arm to assist in part sorting and NDT scanning within airline operations, and a MIRTE robot to assist with barn safety for farmers working in cattle forms. Students are provided with Gazebo simulations of a simple environment and the representation of their robot through GitLab groups. They must create their own ROS nodes on top of the existing packages they have either received with the simulation or added them-selves. They use the same GitLab groups for version control and to store their documentation.

2.4 Didactic Approach

The MSc Robotics, which this course is part of, was established using the vision of Biesta (2021). He proposes an educational framework based on three key com-ponents - qualification, subjectivation, and socialization. In this project, students show qualification and further develop themselves in the subjectivation and socia-lization components. For the project, a Problem- Based learning approach has been chosen. As this is a Master's level course and students are assumed to have been sufficiently exposed to project-based education in their bachelor's, the most mature format within this segment as detailed by de Graaf and Kolmos (2003) has chosen, that of the Problem Project. This type of project is characterized by students being given a problem as a starting point (in our case by their industry client) which determines the choice of disciplines and methods to be used. The staff's role is to ensure the problem fits within the course's wider frame and to facilitate students with additional knowledge and skills training on a need-by-need basis.

This also means limited time is formally scheduled. The 8-week course has a workload of 140 hours per student (15-20h per week) of which only 50 are formally scheduled, with less than half of that 50 hours with formal activities. Students are expected to independently plan the project as a group within the framework and milestones given. As the course started under COVID-19 restrictions, many of the workshops and instructions lectures were offered in a blended format. As this seemed to fit the need for independence within the project, this concept of offering as much of the supporting knowledge as online knowledge clips has been kept. Only the (inter)active workshops and assistance with robot and ROS instruction were introduced as face-to-face moments of knowledge transfer.

2.5 Reflection and Transferable skills

To address the Transferable and Interpersonal Skills learning objectives, students work on a personal development reflection assignment during the course as a natural follow-on from the Vision and Reflection course, starting from day 1. In addition to their technical expertise role, students are asked to investigate and reflect on what their natural project team role is. They are also asked to reflect on their strength and weaknesses and pick roles to fulfill within the team during the project. To ensure every student gets a chance to develop and experiment with team roles, teams are encouraged to rotate roles per sprint. To help them reflect and to learn to give and receive feedback students all follow a workshop on Peer feedback and cultural differences, offered by an external party. There is a deliberate focus on cultural differences given that a third of our students do not have a Dutch educational background. To allow them to practice giving feedback, use is made of peer evaluations, a form of peer assessment aimed at qualitative feedback on performance within teams (van Helden et al 2023). Students are asked to complete two peer evaluations during the project and to reflect on how they dealt with the feedback they received as part of their personal reflection chapter at the end of the project, for which they receive an individual grade. To assist in project management skills, students are introduced to the basics of project management including Agile in a workshop, where groups work together in developing a Work Breakdown Structure and a Gantt chart as living documents to be used throughout the project.

2.6 Course Experience and Fine Tuning to date

After the first editions of the course, student feedback was gathered through an evaluation panel discussion with four students. The students recognized the value of gaining experience working with real-world robots and transferring from simulation to the real world, which they found relevant to their academic and industry aspirations.

The students also suggested that the course name appeared to reflect that they would be collaborating with students from other faculties, beyond robotics alone, which will result in a name change in the future. Students also recommended improving the clarity and usefulness of the human-robot interaction specialist role. As a result, all assignments now involve the presence of a human in the testing space to enhance this role. An experiment using Scrum as a project management tool was carried out in edition 2 which did not work well for students and staff and has since been replaced by Agile. The educational format of a course, which has a defined end, does not fit within the Scrum philosophy of a continuous cycle of software development. Also, the reporting was adapted to fit an agile way of working, aiming to reduce over-reporting. Students also commented they felt the workload exceeded the 5EC given for the course (140h). The course staff is unsure whether students spend more than 140 hours, or if they underestimated what spending 140 hours in 8 weeks involved. To inform students better about the expected workload, a breakdown of expected hours per activity has been added to the introduction for 2022-2023 and the workload is a key focus in our study.

Initially, no industry clients were involved. The students suggested involving real companies to increase the relevance of client meetings and project urgency, an opinion that was shared by the staff. From the second run onward, four companies participated as clients, which was experienced as positive by staff, students, and clients alike, although a critical selection of the type of client is needed. Hence a set of criteria and standards for industry assignments in the course were developed. Other practical problems encountered by staff were the in-house availability of robots, dedicated robot-trained staff, as well as lecturers in preparing, facilitating, and grading the course, whilst still fine-tuning the course design. In the feedback sessions of the first 2 years, there were several elements of the course that were seen as positive by students, staff, and company representatives alike. Working on a project in robotics that is not fully defined is seen as fun and important. Secondly, students found the variety of projects inspiring. Thirdly, the extensive and timely offered feedback is much appreciated by students. Course staff members can see feedback is being accounted for resulting in improvements. Lastly, students appreciated having to list their personal goals for this course in their report. Since this resides in the very first chapter, they are reading them every time they open their report to work on a new iteration.

3 COURSE EVALUATION 2022-2023

Now that the course is in its third year, and both staff and content maturing within the course, we performed a small study among all students in the course, to see if the students felt the course is now fully fit-for-purpose, constructively aligned, and is helping them prepare for the next more individual phase of their Master’s programme and their future career.

3.1 Research Questions & Methodology

The main research question for this study is: What can be learned from student feedback and perceptions regarding the course's Learning Objectives and the overall running of the course? An additional research question is: How did the course contribute to your personal and professional development as a future Robotics engineer? After obtaining ethical permission, all 101 students that enrolled in the course in April 2023, were sent a request to part in an anonymous online questionnaire after the end of the course in June 2023. As the researchers are also lecturers in the course, the questionnaire was designed such that no personal identifiable data was collected, and students were assured that their participation was voluntary and in no way affected their grades for the course. A total of 42 students responded resulting in a response rate of 41.5%.

3.2 Results

The results of the survey are informative and somewhat unexpected by the staff. The students are clearly unhappy with the way the project is organized and in particular the workload. Overall the students graded the project 5.2/10 (N=39, SD=1.84). When asked how many hours on average they spent per week on the project (N=39), 67% indicated they spent more than 25 hours per week, with 5% indicating they spent 10-15 hours per week and 28% 20-25 hours. When asked how much time they had expected to spend students indicated an average of 16 hours (N=39 SD=3.96) which was in line with what was communicated to the students. Students were also doing other courses during the project accounting for an average of 8 EC (N=39, SD 4.69). Also, the answers to the open questions clearly indicated that the high workload was really experienced as problematic for the students.

When asked about the organization and structure students are clearly negative with only 30% listing this as positive (See part I, Table 1 in Appendix for detailed results), even though they are positive about the alignment of and information available within the course. Interestingly 26% strongly disagree that the course has the right level of difficulty whilst another 26% agree with this statement. When asked about communication, feedback, and support by staff and clients, students are clearly also more positive (See part II). With regards to the freedom they enjoyed and whether more mandatory moments or more meetings with staff were needed, students overwhelmingly indicated they were happy with the current situation with limited mandatory meetings. There is however, a large minority of students (40%) that would like a weekly meeting with a staff member as can be seen from part III. Students were moderately positive about the attainment of the learning objectives. (See part IV) We also asked how useful students found the workshops and (video) lectures during the course. Students found the company visits really useful, and to a lesser extent the introduction and systems architecture lecture and the ROS and Presentation workshops (See Part V). All others score poorly and seem to be only useful for a few and not for others or may simply be less popular to engage with when under time pressure. Similar scores can be seen in Part VI when asking students about their opinion on the reflection components in the course which varies from mildly positive to very negative especially when it came to the mandatory intercultural peer feedback workshop. Reflection also needs time and mental capacity available to work and be seen as valuable (Hermsen et al 2022).

4 DISCUSSION

It is clear from the results of the study, that action has to be taken to reduce the workload experienced by students and/or increase the number of EC allocated to the course. As the latter is likely unfeasible within the programme at short notice, efforts must be made to identify areas where students spend time unnecessarily. Also, student (activity) monitoring during the project must be increased. Staff were taken by surprise by the hours reported and by the dissatisfaction with the structure and organization of the project as the excessive number of hours or lack of structure and organization never came up in any of the interactions staff had with students during the course. Hence no interventions could be staged. This dissatisfaction likely grew over time coming to a head in the last two weeks. From the reports and self-reflections, it also became clear that some groups went rather overboard by overdelivering on software and robot functionality and using many new (time-consuming) tools to beautify their presentations and reports, while other groups likely lost time due to the breakdown of internal group communications or not asking for help when they were stuck. In addition, this was the first time for students to have to rely on each other's contributions with many in the self-reflections indicating they often still tried to also involve themselves in the work of others which may also have contributed to a higher workload. Yet at the same time students like the freedom and independence they are given during the project. Weekly progress meetings without students being limited in their freedom may aid in being able to intervene when excesses threaten to occur but would increase the staff workload considerably. There is evidence in the open questions that not all students are equally well versed in programming in ROS and that this may also be a contributing factor to some students finding the course difficult, also contributing to the high workload.

In addition, the scheduling is heavily affected by the number of Dutch Public Holidays in that period. Reorganizing the schedule by moving introductory and preparatory activities to the quarter before and creating more online & video resources will limit the number of mandatory sessions and allow each student and group to make use of them on a needs basis and will hopefully lead to a reduction and a more even distribution of the workload as well as room for the necessary reflection. Finally, the project is very reliant on the reliability of the robots and the quality of the simulation environments of the robots. Actions being considered are limiting all industry assignments to use the same simple robot with a variety of manipulators (MIRTE - a TU Delft in-house mini-robot, see mirte.org) allowing each group to have their own robot and manipulators (and have spares) as well as investing in developing high-quality simulation environments that are tried and tested well in time for the project start. It is clear that further research will be needed.

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APPENDIX 1: DETAILED STATISTICAL RESULTS COURSE EVALUATION

Table 1: Detailed statistical results course evaluation. Blue cell indicative of mean and Bold indicates the highest percentage of a statement

		Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Agree	Strongly Agree	N	Mean	SD
I. Course Organization and Structure	There is a clear connection to prior knowledge	2.38%	4.76%	14.29%	**59.52%**	19.05%	42	3.88	0.85
	The structure and coherence of the course are good	23.81%	21.43%	21.43%	**33.33%**	0,00%	42	2.64	1.17
	The organization of the course is good	16.67%	**33.33%**	19.05%	30.95%	0,00%	42	2.64	1.09
	The content of the course is relevant	4.76%	7.14%	21.43%	**45.24%**	21.43%	42	3.71	1.03
	The course has the right level of difficulty	**26.19%**	16.67%	19.05%	**26.19%**	11.9%	42	2.81	1.38
	The schedule, deadlines, and deliverables are clear	11.9%	9.52%	19.05%	**45.24%**	14.29%	42	3.40	1.20
	The Brightspace page contains all relevant information	4.76%	14.29%	30.95%	**38.1%**	11.9%	42	3.38	1.02
	The manual and the template contain all the necessary information	9.52%	16.67%	23.81%	**45.24%**	4.76%	42	3.19	1.07
	The grading criteria are clear and clearly linked to the LO	26.19%	28.57%	9.52%	**33.33%**	2.38%	42	2.57	1.26
		Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Agree	Strongly Agree	N	Mean	SD
II. Communication and Feedback by Staff and Client	The communication by staff via email or Brightspace in the course is clear	2.56%	10.26%	10,26%	**64.1%**	12.82%	39	3.74	0.9
	There is sufficient technical support available for the software simulation	7.69%	28.21%	**30.77%**	**30.77%**	2.56%	39	2.92	1
	There is sufficient technical support available for the robots	10.26%	**23.08%**	**23.08%**	**23.08%**	20.51%	39	3.21	1.28
	The Discussion board on Brightspace is a useful place to ask questions	18,42%	10.53%	**50,00%**	18.42%	2.63%	38	2.76	1.04
	The response to questions (via email or discussion board) was timely and of good quality	2.56%	5.13%	33.33%	**41.03%**	17.95%	39	3.67	0.92
	Sufficient and timely feedback on intermediate products is given during the course	7.69%	15.38%	17.95%	**48.72%**	10.26%	39	3.38	1.1
	The Peer feedback in Gitlab is useful	12.82%	23.08%	12.82%	**38.46%**	12.82%	39	3.15	1.27
	It is important to have a real (industry) client	5.13%	10.26%	7.69%	**38.46%**	**38.46%**	39	3.95	1.15
	The client provided sufficient information on the assignment and the robot	12.82%	17.95%	12.82%	**43.59%**	12.82%	39	3.26	1.26
	There are sufficient contact moments with the client	25.64%	28.21%	15.38%	**28.21%**	2.56%	39	2.54	1.22
		Strongly Disagree	Somewhat Disagree	Neither agree nor disagree	Agree	Strongly Agree	N	Mean	SD
III. Independence and Oversight	The current freedom of running the project with only mandatory attendance at workshops, and presentations is fine	10.26%	20.51%	7.69%	**30.77%**	**30.77%**	39	3.51	1.38
	Too many people are not doing enough. Please require attendance during all scheduled sessions	**46.15%**	25.64%	10.26%	12.82%	5.13%	39	2.05	1.24
	Planning and doing everything by ourselves and only receive intermediate feedback on reports and review presentations and get answers to our questions from staff is fine	12.82%	10.26%	20.51%	**30.77%**	25.64%	39	3.46	1.32
	There is insufficient staff support. A dedicated member of staff should meet with each group once a week	23,08%	5.13%	**28.21%**	23.08%	20,51%	39	3.13	1.42

		Not well at all	Slightly well	Moderately well	Very well	Extremely well	N	Mean	SD
IV. Attainment of Learning Objectives	Define a problem definition and its corresponding requirements	12.82%	15.38%	30.77%	**35.9%**	5.13%	39	3.05	1.11
	Design relevant (robot) solutions in the field of robotics by integrating knowledge on opportunities, trends, and societal aspects	15.38%	17.95%	33.33%	28.21%	5.13%	39	2.9	1.13
	Produce a robot solution that meets the specifications and considers sustainable, safety, ethical, economics, law, human, and other relevant societal aspects	20.51%	25.64%	30.77%	20.51%	2.56%	39	2.59	1.1
	Use functional architecture for planning and communicating robot software	12.82%	12.82%	28.21%	**43.59%**	2.56%	39	3.1	1.08
	Communicate the multidisciplinary robot solution in a clear way, both orally, in writing, and in code documentation	15.38%	10.26%	23.08%	**43.59%**	7.69%	39	3.18	1.2
	Formulate and adjust learning goals on personal development	20.51%	15.38%	38.46%	20.51%	5.13%	39	2.74	1.15
	Reflect on one's own competencies (e.g.,Teamwork, Leadership, Entrepreneurial thinking, Strategic multidisciplinary problem solving) and development in these and determine where personal learning goals & interests lie	17.95%	12.82%	38.46%	20.51%	10.26%	39	2.92	1.21
	Show to use feedback to improve one's own performance or the performance of others	12.82%	20.51%	25.64%	**38.46%**	2.56%	39	2.97	1.1
	Apply structured multidisciplinary software project management, with the use of different team roles and responsibilities	20.51%	23.08%	28.21%	25.64%	2.56%	39	2.67	1.14
		Not at all useful	**Slightly useful**	**Moderately useful**	**Very useful**	**Extremely useful**	**N**	**Mean**	**SD**
V. Usefulness of Workshops and (video) lectures	Introduction Lecture	5.88%	23.53%	32.35%	29.41%	8.82%	34	3.12	1.10
	Company Visit	5.71%	5.71%	25.71%	42.86%	17.14%	35	3.51	1.04
	ROS workshop	16.67%	25.00%	25.00%	**27.78%**	11.11%	36	3.08	1.66
	Project Management Workshop	22.22%	41.67%	30.56%	8.33%	2.78%	36	2.44	1.02
	Systems Architecture Lecture	11.11%	22.22%	38.89%	22.22%	11.11%	36	3.17	1.36
	Peer Feedback Workshop	**50.00%**	25.00%	13.89%	16.67%	0.00%	36	2.08	1.32
	Presentation Workshop	22.22%	36.11%	19.44%	27.78%	2.78%	36	2.78	1.48
	Video Lecture Documentation	25.00%	27.78%	**30,56%**	8.33%	2.78%	36	2.19	1.06
	Video Lecture Action Classes	16.67%	33.33%	19.44%	8.33%	5.56%	36	2.03	1.18
	Video Lecture Debugging	16.67%	25.00%	**36.11%**	11.11%	5.56%	36	2.47	1.13
		Strongly Disagree	**Somewhat Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly Agree**	**N**	**Mean**	**SD**
VI. Personal Development	The personal reflection assignment in the course is a good continuation of the Vision and Reflection course	20.51%	20.51%	25.64%	**28.21%**	5.13%	39	2.77	1.21
	Being assigned a specialist role helped me develop a better view of where my strengths and interests lie	25.64%	17.95%	15.38%	**33.33%**	7.69%	39	2.79	1.34
	Being able to try out different team roles, such as coordinator, helped me develop a better view of where my strengths and interests lie	**30.77%**	15.38%	23.08%	25.64%	5.13%	39	2.59	1.3
	The workshop on Peer Feedback helped me develop my reflection and feedback skills	**43.59%**	15.38%	25.64%	12.82%	2.56%	39	2.15	1.19
	Giving and receiving feedback, helped me develop my reflection and feedback skills	12.82%	12.82%	30.77%	**30.77%**	12.82%	39	3.18	1.2
	The personal reflection assignment within the project helps me in my personal development toward an independent engineer	**38.46%**	12.82%	17.95%	23.08%	7.69%	39	2.49	1.39

AN EMBODIED COGNITION APPROACH TO COLLABORATIVE ENGINEERING DESIGN ACTIVITIES

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ABSTRACT

Higher educational institutions have broadly adopted Collaborative Engineering Design (CED) activities to prepare students for complex problem-solving in multidisciplinary settings. These activities are non-linear and mediated by various social practices and tools. Therefore educators might struggle in facilitating the achievement of specific learning goals. Embodied cognition is an approach that explains non-linear behaviour through orgamism-environment interactions and might therefore provide educators with insights on how to prompt students towards desired actions in CED activities. According to embodied cognition, we learn through actions that emerge as a response to a problem (task) and environmental constraints. Educators can guide students' behaviour by proposing tasks and adapting the environmental constraints of a learning situation, thus creating a field of promoted action. In this paper, we outline the progress of a design-based research in which insights from embodied cognition are implemented to promote desired student behaviour in CED activities. We report on the results of our problem-exploration phase. A systematic literature review and focus groups with students revealed that students are often hesitant to adopt new practices and tools that could potentially improve their collaborative design process. Next, we propose three theory-based design principles in which the task and environmental constraints are leveraged to foster the adoption of practices and tools and apply them to CED activities. Finally, we will share preliminary observations of the learning processes triggered by the designed activities and outline the directions for future research.

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1 INTRODUCTION

Contemporary challenges require engineers that are able to solve complex engineering problems in a multidisciplinary context (Winberg et al. 2020; Hadgraft and Kolmos 2020). Higher educational institutes often adopt Collaborative Engineering Design (CED) activities to foster the development of technical and non-technical skills desired by industry (Picard et al. 2022; Shuman, Besterfield-Sacre, and McGourty 2005). However, problem-solving processes during CED activities are non-linear and continuously mediated by various social and material resources (Vujovic and Hernandez-Leo 2022). This can make it challenging for educators to facilitate the development of specific learning objectives. Theories on embodied cognition, such as theories on dynamical systems (Shvarts et al. 2021; Guevara, Rojas Ospina, and van Geert 2020), can potentially provide insight into how to guide students towards desired behaviour in non-linear problem solving. A *functional dynamic systems approach* centralizes organism-environment interaction in the learning process. We learn through actions, that emerge as a response to a problem and the affordances and constraints of the environment (Bernstein 1996; Abrahamson and Sánchez-García 2016). Researchers investigated how the design of a task and learning environment can guide students' self-exploration and discovery during problem solving activities in the domains of mathematics (Abrahamson 2013; Shvarts and van Helden 2022) and science (Lindgren et al. 2016; Enyedy et al. 2012). Still, the engineering domain remains underexplored (Weisberg and Newcombe 2017), while it was shown that bodily interactions are central to discovery and meaning making processes during CED activities (Davidsen, Ryberg, and Bernhard 2020; Bernhard et al. 2019).

In this paper, we will report on the progress of a design-based research in which we investigate how a functional dynamic systems approach can be leveraged to foster productive collaborative behaviours, including the use of project management practices and associated tools. Design-based research is a methodological framework in which the design of a learning environment is intertwined with testing and developing theory (Bakker 2018; McKenney and Reeves 2019). It involves the iterative development of solutions to educational problems in real-world contexts, following the reoccuring activities of exploring a problem and available theoreretical perspectives for solving the problem, designing a theory-based solution, testing the solution in a classroom setting, and analysing the results to inform theory and practice. The main contribution of this paper is the design of a theory-based CED activity. We will outline the rationale for the designed solution. Furthermore, we will share preliminary observations from the first classroom experiment and reflect on steps that will be taken in the future

2 PROBLEM EXPLORATION

We have used literature and insights from practice to identify problems that occurred frequently within CED activities. We conducted a systematic literature review on the implementation of collaborative learning in engineering design activities (van Helden et al. 2023). It was found that students were often hesitant to use new tools in CED activities, even when these tools offered functionalities that could potentially improve their collaborative design practices. We encountered a similar problem when analysing a Master-level CED course at the Faculty of Aerospace Engineering, Delft University of Technology (van Helden et al. 2022). During the Collaborative Space Design Project (CSDP), we aimed to teach students new practices for design (e.g. concurrent engineering) and project management (e.g. Scrum). Even more, we offered them an environment, called the Collaborative Design Lab (CDL), which holds a variety of industry-relevant tools that enable new ways to collaboratively design and manage a project. Its most salient features include: 1) Nureva Span Wall (Nureva n.d.), a large digital whiteboard with touch screens for projecting and organizing information, 2) COMET (RHEA Group n.d.), a tool suitable for implementing an integrated design model, 3) and a conferencing tool that allows outsiders to interact with a team in the CDL. When conducting focus groups with students, it was found that they relied on intuitive approaches to design and project management they already knew. They did not use the tools in the CDL, neglecting the role of these tools within the tasks of managing and conducting collaborative design projects. Still, all student teams acknowledged that they could have managed their project in more efficient ways if they had made use of a more structured approach to project management.

3 THEORETICAL PERSPECTIVE

A traditional way to introduce new practices and tools that might assist those practices is through step-by-step tutorials that explain or demonstrate desired behaviour (i.e. we show, you imitate). The assumption is that by structuring and breaking-up content it is easier for students to mentally process the to-be-learned practices. However, from an embodied cognition perspective, researchers have argued that learning new practices and discovering how tools can support these practices cannot be reduced to step-by-step routines, as practices are holistic and emergent processes (Dreyfus 2007). Instead, learning environments should facilitate self-discovery of new practices and the role of tools in them through action (Abrahamson and Sánchez-García 2016; Shvarts et al. 2021). Let us illustrate this with the example of a child learning to eat with a spoon. This new practice is not learned through a step-by-step breakdown of what the child should be doing but through enactment. It starts with a need to perform a certain action which can be as simple as the child being hungry and wanting to eat. The amount of actions relevant for solving this problem is restricted by the task at hand. When eating a plate of rice, the child could rely on actions she can already perform: eating with her hands. However, if we change rice for a bowl of soup it will no longer be possible to use her hands for eating. The child is pushed towards finding other ways of bringing the food to her mouth such as using the spoon in front of her. Still, it can be that the child is not yet capable of immediately using the spoon to fulfill the task. In this case, the environment can be altered to facilitate the self-discovery of new practices. For example, the regular spoon can be replaced with a children's spoon that has a handle with finger grips, to make it easier and more inviting to hold the spoon. The task and environment guide the child towards performing new actions and thus expanding her action possibilities. Initially, theories on embodied cognition explained only learning at a motor level, such as learning to eat with a spoon. However, researchers expand those theories and create embodied learning materials in which the task and environment guided students when learning seemingly less tangible content, such as mathematical (Abrahamson 2013; Shvarts and van Helden 2022) and scientific (Lindgren et al. 2016; Enyedy et al. 2012) concepts. An important difference between learning to eat with a spoon and learning, for example, mathematics, is that for mathematics we also want the child to describe and explain what she is doing. In the current study, we will build on this work and expand toward a new problem that is essential to CED: how to manage a project.

4 DESIGN OF PROBLEM SOLUTION

In this section, we will describe the rationale and the design of our learning activities aimed at fostering students' adoption of Scrum as a project management practice and the use of associated tools. In section 4.1 we describe the selected learning content. In section 4.2, we will introduce three Design Principles (DP) derived from literature on embodied cognition. In section 4.3., the designed activities will be described and linked to the DPs. Furthermore, we will introduce our Hypothetical Learning Trajectory

(HTL) (Bakker 2018), which is the analytical instrument for evaluating the designed activities.

4.1 Learning content: Scrum and tools

Managing complex projects is an important skill for engineering students [source]. We suggest "re-inventing" Scrum (Schwaber and Sutherland 2020) as a useful approach to learning project management. Scrum is a widely adopted agile approach to project management, existing of three reoccurring phases: 1) forethought, 2) execution and monitoring, and 3) reflecting. The forethought phase concerns project planning and starts with translating customer requirements into tasks. The overview of all tasks for the project is called a project backlog. There are too many tasks in the project backlog to be tackled at once, so they will be divided over multiple sprints. At the beginning of each sprint, tasks from the project backlog are selected. To create an attainable sprint planning, it is important to roughly estimate the duration of each task, prioritize tasks, and formulate the " definition of done" (i.e. when a task is finished). During the execution and monitoring phase, the team works autonomously on the tasks from the sprint backlog. To continuously monitor the progress, a Scrum board is used. This is a board displaying the tasks from the sprint backlog and their status: "open", "in progress", or "done". In addition to this, every day starts with a short daily Scrum meeting, in which all team members give an update on the status of their intended tasks. At the end of the sprint, it is time for the reflection phase. In Scrum, there are two types of reflection. First, there is the sprint review, in which the team evaluates their product with their customer and revises the project backlog. Second, the sprint retrospective, aimed at reflection on the collaborative process, is an occasion in which all team members can provide suggestions to optimize the Scrum process. After finalizing the reflection phase, a new sprint can be planned and the cycle starts again.

In the CDL there are tools available to support the Scrum process. The most important tool is the Nureva Span Wall: a large digital whiteboard with touch screen. This wall can be used as a shared visual point of reference during the three phases of the Scrum process. There are plenty of software tools available for project management. However, in this study we aim for students to self-discover Scrum as a response to the problems they face during our workshop. For example, we want them to think about what they would like to monitor and what structure would support this. In other words, we want them to invent their own Scrum board, rather than use a given structure. For this purpose, we decided to introduce Miro(Miro n.d.), which is a software tool that provides a blank canvas on which team members can create and structure content.

4.2 Design principles and hypothetical learning trajectory

For the design of our learning activity, we drew on theories of embodied cognition. Specifically, we focused on a functional dynamic system approach, as this theory explains how new tools become incorporated into learners' practices through organism-environment interactions (Shvarts et al. 2021). Following this approach, action is regulated by a functional body-brain system, which is a non-centrally organized system that shows non-linear yet stable behaviour within the constraints of the environment (Guevara, Rojas Ospina, and van Geert 2020).

DP 1: creating a field of promoted action – from problem to action. Following a functional dynamic systems approach, action is central to learning (Shvarts et al. 2021). In this context, action is not a synonym for movement, as actions always emerge as a response to a problem (Bernstein 1996). Actions are thus characterized by the *intentionality* to reach a certain target state. While performing an action, we are continuously interacting with our environment, which holds certain *affordances* (i.e. opportunities for action) (Gibson 1979) but also *constrains* the actions that can be performed. Learning takes place when a task (i.e. problem) and the environment guide us towards performing new actions -- think of the example of the child learning to eat with a spoon. Learning can be supported by narrowing available action possibilities and creating an environment in which students are guided toward performing new (desired) actions: *a field of promoted action*.

DP 2: reflection on action – from naïve to formal. Students perform various actions in order to solve a problem. To connect these new behaviours with formal practices, actions need to be re-described verbally. When prompting students to reflect on their actions, the reflections that emerge are often naïve. An educator can play an essential role in helping students to refine their perspective toward the culturally accepted terminology and inscriptions (Vygotsky 1978; Flood 2018).

DP 3: facilitate transfer – from learning situation to new situation. When educating, we typically aim for students to develop behaviours that transcend the learning situation and are also used in novel situations. This phenomenon, also known as transfer of learning, emerges when a student *recognizes* an affordance for action from the learning situation in a new situation (Greeno, Smith, and Moore 1993; Shvarts and van Helden 2022). We can support students' noticing of invariance between a learning situation and a new situation, by creating similarities between the constraints of the task they need to fulfill and the environment in which they operate.

4.3 Design of learning activities

We will now describe the design of our learning activity, and explain how each of our DPs is integrated. We designed two workshops on Scrum, one forethought and monitoring and one on reflection, that can be implemented in CED courses. In our workshops, we do not provide students with a breakdown of Scrum in advance. In line with DP 1, we give them *tasks* that contain one or more *problems* that can be solved by problem management practices. For example, the first task about planning is to create an overview of what needs to be done before completing the project. For completing this task, multiple problems need to be solved that are all connected to key elements of Scrum, including: 1) knowing which tasks need to be solved (project backlog), 2) which tasks need to be solved first (prioritizing tasks), and 3) if solving these tasks is attainable in the given amount of time (estimating tasks). We expect this will elicit an intentionality to so solve the problem at hand. While doing so, we expect students to use *artifacts* that are available in the environment, including the Nureva

Span Wall and the Miro canvas. Following DP 1, we also introduced environmental constraints to guide students' behaviour. For example, we do not provide a blank Miro Canvas. Rather, we have created virtual artifacts that will help to elicit desired behaviour, such as "working areas" to centrally collect tasks for the project backlog and sprint backlog and "text boxes" to write down tasks (Appendix A). These artifacts do not impose a structure on students, rather they are building blocks for a structure that might emerge for the students when performing desired actions. We implemented DP2, by asking students to reflect on the actions they performed at the end of the workshop. We ask students to construct a timeline in Miro in which they list the actions they performed. To refine their perspective toward the culturally held view, the educator presents them with "sticky notes" with Scrum terminology in Miro and asks them to map the Scrum terms to their own timeline. Finally, we implemented DP 3 by creating continuity between the task and environmental constraints of the Scrum workshops and the design sessions. An example related to the task is that students will have time pressure to deliver their design, as we believe this will sustain the need to estimate the duration of tasks after the workshops. With regard to the environment, we will, for example, turn on the Nureva Span Wall during students' first design session, so that they will be guided into using the wall during their planning activities.

4.4 Hypothetical Learning Trajectory

To investigate whether desired actions were triggered by the designed activities, we created an HTL, which is an analytical instrument that connects a learning task to expected observable behaviour. For illustration, a fragment of our HTL is shown in Table 1. In this HTL, we have outlined the *workshop tasks* (column 2), the *intentionality* (column 3), the *problems* students have to solve to complete a task (column 1), and the *constraints* of the environment used to guide them toward desired behaviour (column 4). For each problem, we have outlined the behaviour that is expected to emerge during the workshop and stabilize during the design sessions (column 5). Next to this, we have connected each problem to a formal Scrum concept (column 6) and to task and environmental constraints that should facilitate transfer during the design sessions (column 7).

5 CLASSROOM OBSERVATIONS

We have implemented the workshops as described in the HTL within the CSDP. In this course, teams of seven to nine students collaboratively design a solution to a complex and open-ended engineering problem. Over a period of eight weeks, students have weekly co-located design sessions in the CDL. The workshops on Scrum took place in the first two weeks of the course. Our goal was to elicit the practices that were outlined in the HTL during the workshops (learning situation) and the design sessions (transfer situation). Two out of six student teams participated in our study.

Table 1. Fragment of HTL. (DP 1 = blue; DP 2 = green, DP 3 = orange)

Problem	Workshop task	Intentionality	Environmental constraints	Expected stabilized behaviour	SCRUM concepts	Transfer to design sessior
How does everyone know what tasks should be done?	Create an overview of what needs to be done for your project, based on the conversation you had today with your project coach.	Collective overview of tasks are needed to finish project and why this task needs to be fulfilled.	Used artifacts: Nureva Span Wall, Miro board Environmental constraints: in Miro "working area" that can be used to collect tasks for project backlog and "text boxes" that can be used to write down tasks and move them to project backlog.	1) A "working area" in Miro is selected, that will be used as a space to collect tasks for the product backlog; 2) Mention task that should be fulfilled before project completion; 3) Mention what the added value (increment) is of this task for the customer; 4) Write down tasks and increment in "text-box" in Miro and put task in project backlog; 4) repeat 2 and 3.	"Creating a project backlog" "increment"	*Environmental.* When students enter the CDL, the Nureva Span Wall will be opened, and their self-made Miro Template i shown *Task:* Customer requests a project plan
How does the team know which tasks should be done first?		Collective overview of what is the order in which tasks should be done.	Used artifacts: Nureva Span Wall, Miro board Environmental constraints: in Miro different "visual markers" including text, numbers, colours.	1) Discuss order of tasks 2) Create or use existing "visual markers" to represent relative priority of each task (e.g. numbers, or change of visual order)	"Prioritize items"	*Task:* Customer requests a project plan
How does the team know if the task list is attainable?		Collective overview of duration of tasks.	Used artifacts: Nureva Span Wall, Miro board Environmental constraints: in Miro different "visual markers" including text, numbers, colours.	1) Discuss rough duration of tasks 2) Create or use existing "visual markers" that represent relative duration of each task (e.g. order or colours that reflect duration)	"Estimate items"	*Task:* Time pressure
From naïve to formal	Individually create a timeline of the actions you have taken to solve the workshop tasks.					
	Merge your individual timelines to one big common timeline, that reflects the actions you have taken as a team to solve the workshop tasks. You have worked on the Miro board, and a structure has emerged. Create a template for this structure in Miro that can be used by another group. Now connect these templates to the timeline. Educator gives students sticky notes with scrum concepts (column 6) on them. Students are asked map these concepts to their template and timeline. Which are similar? Which are not yet covered? Which extra rules have they came up with, that are not part of the scrum sequence?					

Preliminary observation revealed that these student teams showed much of the expected behaviours during the workshops, including creating a project backlog with an overview of tasks, selecting a sub-set of tasks for the sprint backlog, and reflecting on the collaborative process. However, not all desired behaviours were shown during the workshops. For example, we students did not come up with a Scrum board that could be used to monitor complex problems.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we have showcased the progress of our design-based research. We first introduced a problem found in literature and practice: students are often hesitant to adopt new practices and associated tools during CED activities. Next, we presented the design of a learning solution, based on insights from embodied cognition. Preliminary observations revealed promising results, however, also revealed that not all desired behaviors could be observed during the workshop. The next step is to conduct a thorough analysis of the classroom implementation described in the previous section. During this implementation, we gathered audio and video data that will be qualitatively analysed to investigate whether expected stabilized behaviours, as described in the HLT, emerged during the workshop and design sessions. Based on the conclusions derived from this analysis, the DP's and HTL will be revised and again evaluated in a classroom context. Even more, we aim to expand our intervention to new tools and practices, such as the use of concurrent engineering practices and the use of tools for implementing a model of a system or process wherein all specialisms together contribute to creating a design, i.e. an integrated design model.

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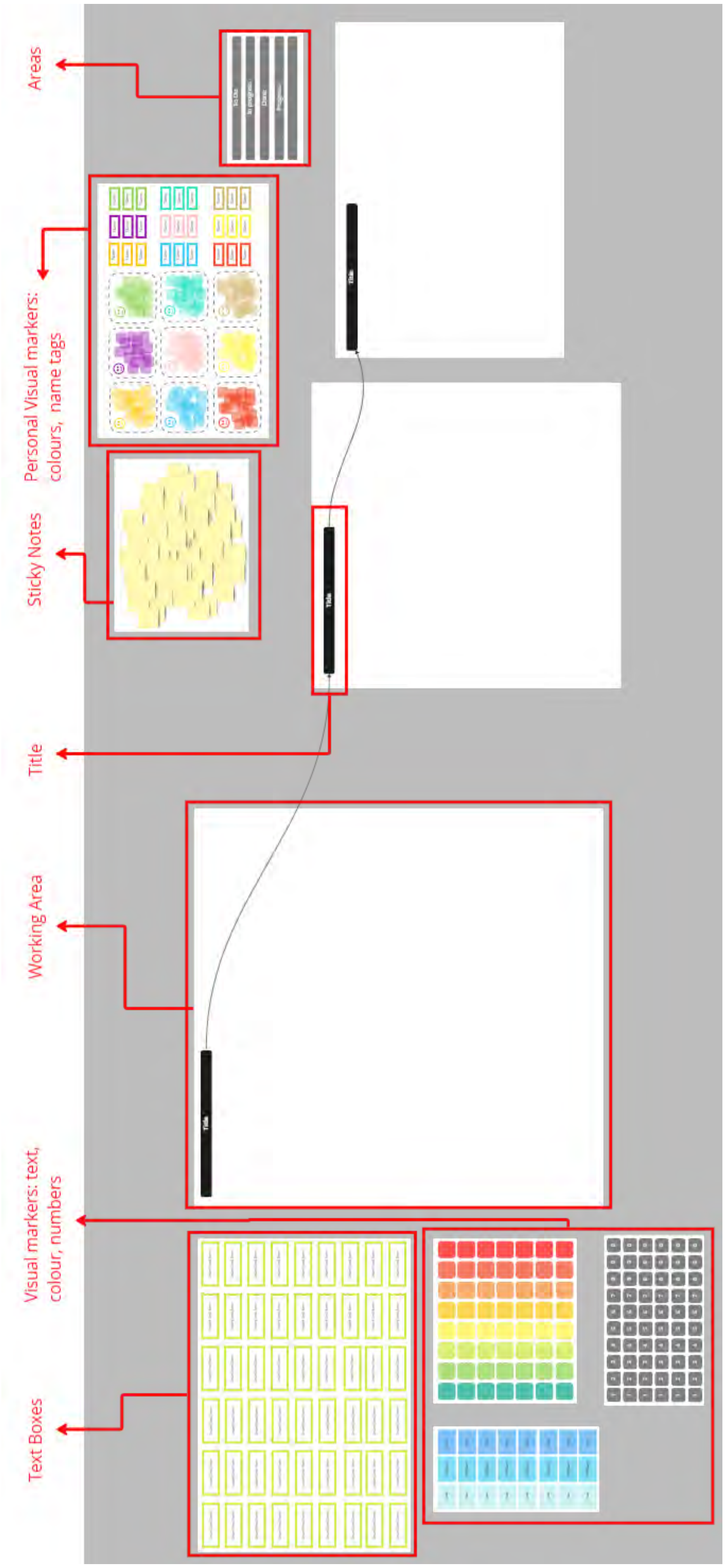
APPENDIX A – EXAMPLE OF ENVIRONMENTAL CONSTRAINTS IN MIRO CANVAS



Improving Employability with a Competence Profile

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ABSTRACT

Employability has become a central focus for Higher Education Institutions. The European University Association's report states that graduates should acquire a mix of transversal and discipline-specific skills. An educational approach known for providing students with this is Problem-Based Learning. An institution known for successful implementation of PBL is Aalborg University located in Denmark. In this paper we will look at an initiative they have recently launched to improve the employability of their engineering graduates. Employability can be defined from different perspectives. In this paper we develop a framework where employability is viewed from three different perspectives. 1) Internal values, beliefs and aims for a future career, 2) Skills and competencies, both transversal and subject specific, 3) External factors such as the state of the labour market and utilising one's knowledge and skills to navigate it. The initiative introduced here focus on perspective one and two. Here the students attend a mandatory competence profile workshop, in which they must hand in a competence profile where they describe their competences from four predetermined sets of competences: reflective, problem-oriented, interpersonal, and structural. This is done in a 3-step model where the students interview each other, then provide peer feedback to their fellow students' profiles and then receive feedback from staff on their individual profile. The students complimented the initiative and the peer-feedback session. This confirms previous research done in relation to how to facilitate reflection among students in higher education, where the recommendation is to do it as an iterative process.

1 INTRODUCTION

1.1 Background

From 2000-2020 the global number of students who enrolled in higher education has more than doubled (“Higher Education Figures at a Glance” 2020). In North America and Western Europe the number of students enrolled in higher education from 2000-2020 has increased by 20 % (“Higher Education Figures at a Glance” 2020). In order to make sure there is employment for all these graduates, employability has become a central focus for Higher Education Institutions (HEI) (Cheng et al. 2022). In this context the European University Association’s report: “Meeting skills and employability demands” (hereafter referred to as the EU report) states that graduates should ideally acquire a mix of transversal and discipline-specific skills (McSweeney 2021). An educational approach known for providing students with this mix of transversal and discipline-specific skills is Problem-Based Learning (PBL) (Litzinger et al. 2011). An institution known for successful implementation of PBL in their engineering educations is Aalborg University (AAU) located in Denmark (Graham 2018, 20). In this context HSB Economics has on behalf of AAU produced a report showing how companies rate engineers from AAU. The report shows that employers are happy with the engineers that have graduated from AAU, they have a good reputation in the industry and they have a good mix of transversal and discipline-specific skills. One suggestion for improvement of the graduates is that they are more geographically flexible in terms of employment another is that they become better at communicating their skills and competences to potential employers (HBS Economics 2022). Another internal report compares the time it takes for AAU-graduates to get their first job with the rest of the HEI’s in Denmark, this report shows that students from AAU, 7 quarters after graduation lacks behind most other HEI in Denmark (Aalborg Universitet 2020). This becomes a problem, as AAU is a public funded university and the number of seats they can offer for students at different programs is among other things determined by the education’s unemployment rate compared to the general unemployment rate. A comparison of the unemployment rate is conducted 12-23 months after graduation, thus if one program’s unemployment rate is higher than the average unemployment rate this may affect the number of seats the university can offer for subsequent years. This has motivated the university to start initiatives that improve the employability of their graduates. In this paper we will look at one of these initiatives and argue from a conceptual perspective about the rationale of this initiative. Later we will include some reflections from experience. We will start by looking at research regarding employability and higher education.

1.2 Defining Employability

Employability research in higher education, has traditionally focused on getting a graduate a job after completion of higher education (Støren and Aamodt 2010). De Vos, De Hauw, and Van Der Heijden (2011) define employability in relation to capabilities of individuals Here the focus is on personal attributes or specific competences into which the individual can construct and communicate herself as “employable”. Brown, Hesketh, and Wiliams (2003) focus on the relative dimension of employability. The critique towards viewing employability as an individual capacity is that it ignores that employability is primarily determined by the labour market, arguing that employability is influenced by social, institutional and economic factors (Sin and Amaral 2017). The social, institutional and economic factors have received attention in relation to ethnicity, gender, social class and disability (McGinn and Oh 2017). Small, Shacklock, and Marchant (2018) emphasize the duality of the perspectives mentioned above, and define employability as:

“The capacity to be self-reliant in navigating the labour market, utilising knowledge, individual skills and attributes, and adapting them to the employment context, showcasing them to employers, while taking into account external and other constraints” (Small, Shacklock, and Marchant 2018, 151)

This links to the EU Report that addresses how employability can have different meanings and foci. One understanding focus on the need to equip students for work, in which the spectrum of definitions ranges from a specific vision of employability in absolute terms and to specific needs from particular professional sectors (McSweeney 2021). Another understanding of employability is focused on the role of higher education in educating the graduates of tomorrow, here the focus is on citizenship and what in Germany and the Nordic countries is called “bildung” the emphasis on the person as a whole, who gains value and insight from a higher education. However, the EU report criticises this dichotomy and states it should not be one or the other, but both understandings that could be relevant to work with. As they state later on: “Therefore, employability is not only defined from the perspective of the labour market or employers, but also from the perspective of who graduates will become in the future as a result of their learning journey in higher education, and how higher education provides for graduates over a career span” (McSweeney 2021, 3). Thus employability seems to contain three perspectives: 1) Internal values, beliefs and aims for a future career, 2) Skills and competencies, both transversal and subject specific, 3) External factors such as the state of the labour market and utilising one’s knowledge and skills to navigate it. As seen in the figure below:

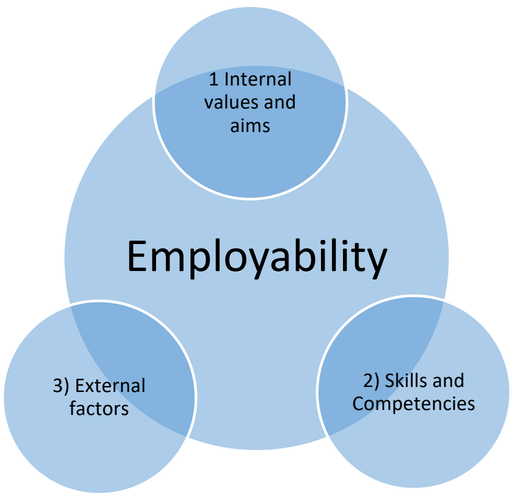


Figure 1: Three Dimensions of Employability

The difference between internal values and skills and competencies, is that perspective one relates to one’s personal values and aims, addressing what kind of person do I want to be and how is this reflected in the types of jobs I seek. Skills and competencies, is more focused on the skills and competences related to one's degree. External factors of the labour market addresses the external factors about a certain degree's prospect of getting work after finished graduation. This might be due to factors beyond the single graduates control.

To operationalize employability further we will briefly introduce Harvey's (2001) writing. Harvey states that the core of all dimensions of employability relates to the: "propensity of students to obtain a job" (Harvey 2001, 98). He further elaborates on five different perspectives of looking at employability:

1) *Job type* Employability is about securing any job, and not necessarily a job related to graduate attributes. For others the focus is on getting a graduate-level job.
2) *Timing* employability is defined by getting a job within a specific period and before there is any need for retraining
3) *Attributes on recruitment* employability signify an ability to demonstrate relevant attributes at the point of recruitment, or alternatively employability refers to a developmental process indicating the ability to develop relevant attributes quickly.
4) *Further learning* some point out the degree is the starting point of the learning process; thus, the most important employability attribute is graduates who are ready for further learning. Others point towards the fact, that the degree is the most important part and then you can add small bits on it afterwards.
5) *Employability skills.* Employability can be understood as the possession of core skills or an extended set of generic attributes that an employer emphasizes (Harvey 2001)

In relation to the case at AAU variable 2 and 3 seems especially important, as the government measures unemployment rates at a specific point in time and industry has recommended strengthening the students' communication skills in relation to their own competencies.

AAU is internationally recognized for their PBL model and how they teach their students both subject specific knowledge and transversal skills, in this perspective collaboration is a big part of the transversal skills. In the past decade collaboration and team work has been prioritized as a highly important skill for engineers (ABET 2016; OECD 2011). This is among other things due to how engineers should tackle complex ill-defined problems due to increased globalization and rapid changes in technological developments (Bass, McDermott, and Lalchandani 2015; Ellis, Han, and Pardo 2019; Lucena 2006; UNESCO 2021; Velmurugan et al. 2023). Teamwork is also mentioned in the literature as important in regard to improving employability (Winberg et al. 2020), thus it might seem contradictory that these candidates have difficulties in regard to their employability. Some mention this might be because of the region into which the university is located. This is the region in Denmark with fewest academic positions, and students might prefer staying in the region instead of moving, as the majority of the students usually grew up in the same region. This links back to the HSBC report, that states graduates should be more geographically flexible in relation to their employment. However, as the university has a campus in Copenhagen, numbers from that campus shows there are difficulties with unemployment compared to other institutions in the capital (Aalborg Universitet

2020). Another point to mention is that students at AAU usually come from non-academic homes (Servant, Schmidt, and Frens 2016) thus they do not have the same social background and network that students from privileged backgrounds might have affecting their networking opportunities after completed graduation. It is however important to remember, that the students do seem to get a job and they are valued by employers, the problem seems to be the time it takes engineers to get a job, which according to the HSBC report could be because they are not skilled in communicating their competences and because they are not geographically flexible. In the following we will describe an initiative, that tried to improve the students abilities to communicate their competencies.

2 INTRODUCING COMPETENCE PROFILE WORKSHOP

2.1 Training the students' communicative competences

We previously introduced the following definition of employability:

"The capacity to be self-reliant in navigating the labour market, utilising knowledge, individual skills and attributes, and adapting them to the employment context, showcasing them to employers, while taking into account external and other constraints" (Small, Shacklock, and Marchant 2018, 151)

Then we mentioned how students at AAU despite being part of an internationally praised model of PBL that teaches students important attributes in relation to employability struggle to find employment within the first two years after graduation and how this affects the number of seats the university can offer different students. We mentioned several aspects that could have an influence on this, but we will now focus on the fact, that students seem to have trouble to utilize and actively communicate the competencies they get by working in a PBL curricula. Thus, we limit ourselves to focus on employability from an individual perspective in relation to the students' competencies in communicating herself as employable and showcase this to employers. In relation to model 1 we work with perspective one Internal values and Aims and perspective two Skills and Competencies. Perspective one refers to what the student want in relation to their future work and perspective two then addresses how they can conceptualise this in relation to their developed skills and competencies. Thus, what is needed in perspective one is reflection and self-awareness of what one wants to work with and then link these to perspective two and develop effective communication strategies in order to actively communicate ones attributes to a third person. The way to practice this among engineering students was with a competence profile workshop at their second semester of their master's studies, which we will introduce in the following.

2.2 The Competence Profile

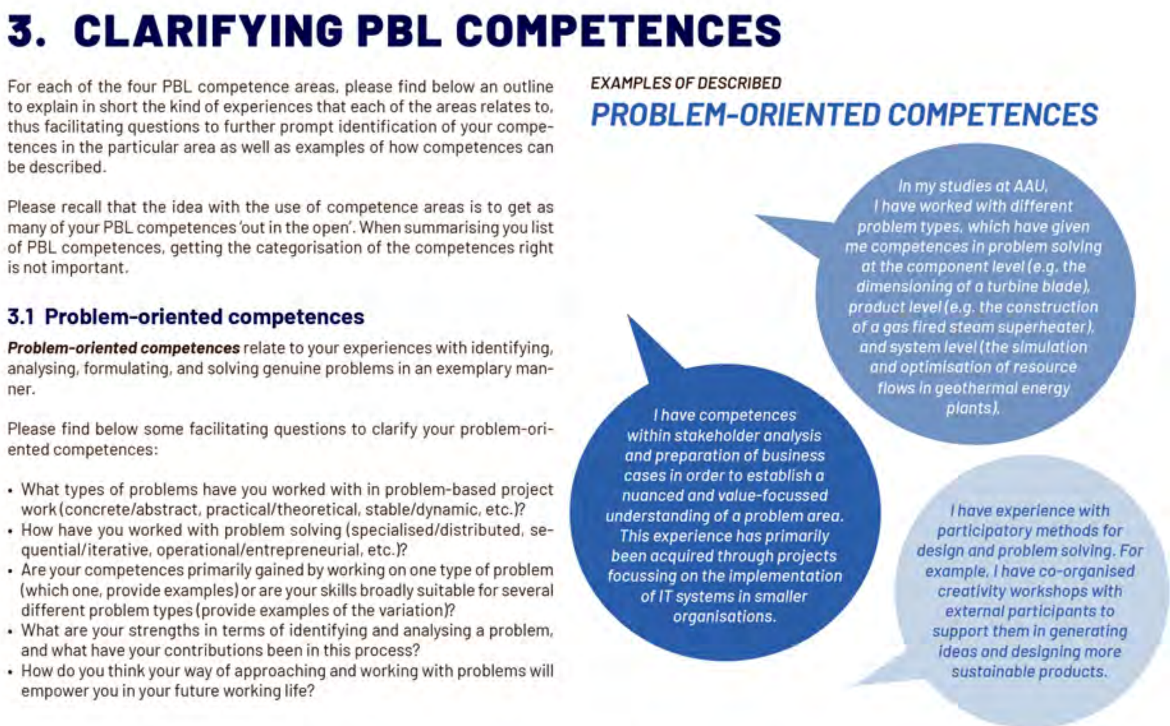
A mandatory workshop was developed to train the students' reflective and communicative skills to improve their employability. The workshop focused primarily on the students' transversal skills as previous research found these types of competences were becoming tacit for the students (Holgaard and Kolmos 2019). Thus an operationalisation of the different types of transversal skills the students develop throughout their study at AAU was developed as showed below:

Figure 2: PBL Aspects related to each of the four PBL competences (Holgaard and Kolmos 2021, 6)

The competences the students have acquired are divided between four main areas of competences: reflective competences, problem-oriented competences, interpersonal competences, and structural competences associated with 12 attributes to each main area of competence as shown in the figure above. The reflective competences are meta competences and present with all competences, as shown in the figure. The problem oriented competences refers to the different problems students encounter through their studies. At AAU students write a project with a point of departure in a problem each semester. The idea behind the reflection of the problem-oriented competences is that the students actively reflect over different types of problems they have encountered throughout their studies, and what sort of competencies they have acquired by working with these types of problems. Earlier in this paper we described how engineers will meet complex ill-defined problems. The problem oriented competences serves as a reflection on how the students have tackled these problems. Another important factor, when encountering these problems is collaboration, which is an important transversal skill. In order for collaboration to be effective interpersonal and structural competences are necessary, especially in an engineering context where a lot of work happens in projects, that requires structuring and planning (Trevelyan 2010). To gain the most out of these competencies experience with them in itself is not enough, an active reflection is necessary in order to determine how to work with these areas and how to transfer this practice to other context (Kolb 2015), thus the reflective competences becomes a meta-competence relevant for all subgroups of competences, as shown in the figure, with the yellow square behind all the other ones. In relation to Harvey's dimension regarding employability, the workshop focus on the attributes relevant for students to communicate to relevant stakeholders, thus the purpose with the workshop is to develop students' reflective and communicative skills. The students' profile should be one page, where they choose one-two attributes from each competence area, and argue for how, they have acquired these competencies and how they have demonstrated these competences in the past.

It is then uploaded on the learning platform Moodle, and they are provided with written feedback from staff. The students' profiles are approved as soon as they upload them, however they receive written feedback from staff where the students get an impression of what worked well in their profile and what needs further work. The students do not have to re-submit their profile, but the exercise provides an opportunity for them, to get an impression of how they have managed to communicate their transversal skills to other stakeholders. Despite the fact that students in principle can upload a paper with one sentence and get that approved, our experience is that this is very rare.

To facilitate the writing of the profile, the students are handed a guide with reflective questions in each main area of competence an example is shown below:



3. CLARIFYING PBL COMPETENCES

For each of the four PBL competence areas, please find below an outline to explain in short the kind of experiences that each of the areas relates to, thus facilitating questions to further prompt identification of your competences in the particular area as well as examples of how competences can be described.

Please recall that the idea with the use of competence areas is to get as many of your PBL competences 'out in the open'. When summarising you list of PBL competences, getting the categorisation of the competences right is not important.

3.1 Problem-oriented competences

Problem-oriented competences relate to your experiences with identifying, analysing, formulating, and solving genuine problems in an exemplary manner.

Please find below some facilitating questions to clarify your problem-oriented competences:

- What types of problems have you worked with in problem-based project work (concrete/abstract, practical/theoretical, stable/dynamic, etc.)?
- How have you worked with problem solving (specialised/distributed, sequential/iterative, operational/entrepreneurial, etc.)?
- Are your competences primarily gained by working on one type of problem (which one, provide examples) or are your skills broadly suitable for several different problem types (provide examples of the variation)?
- What are your strengths in terms of identifying and analysing a problem, and what have your contributions been in this process?
- How do you think your way of approaching and working with problems will empower you in your future working life?

Figure 3: Reflective Questions to Clarifying PBL Competences (Holgaard and Kolmos 2021, 7)

The workshop has been conducted for three years and recently a new format of the workshop has been tested, where the workshop has been divided in three phases.

1. Phase The students interview each other in their project groups following the guide. The students do this themselves without any teachers present. They are provided with a 10-minute pre-recorded lecture to introduce them to the background and format of the competence profile.
2. Phase The students meet with students from other programs with a draft of their profile and receive peer feedback. They have access to a 10-minute pre-recorded lecture on the advantages of peer-feedback and how to provide it. Teachers are present to facilitate the peer-feedback. After this session they upload their profile
3. Phase The students get feedback on their profile and can see a short 10-minute pre-recorded lecture about the importance of targeting their future profiles/CVs to a specific job posting or company.

3 DISCUSSION

Unfortunately due to new ethical approval procedures, we were unable to get the right permissions to provide examples of how students have articulated their competencies in the profiles they have submitted We do however plan to analyse these articulations in a future publication with a new cohort of students. We also don't have permission to present quotes from the survey evaluating the 3-step Competence Profile Workshop format we tested out in 2023. However, from experience we can state that the students who showed up at session two (approximately 50 % of the students did not show up), were satisfied with the peer-feedback session and that the workshop was divided in three parts, here they emphasized the fact they had their own reflective space to write the profile after discussing it with their group members. It should be noted that the workshop has run for three years, and the first two years it was just one physical session where they were introduced to the workshop, asked to interview each other, and then write and submit the profile, after which they would get feedback from staff. This format received a lot of criticism. Lolle, Scholkmann, and Kristensen (2023) states that to secure students' active reflection they need to be triggered by a problem or unusual situation and this is best done in an iterative process. Our experience with this workshop format seems to confirm this.

In relation to employability there are still factors out of our control, concerning how the job market is, and we don't provide information to the students about the job market in relation to their profile. A way to improve their employability could thus be to inform the students where their education/program stand in the job market so the students can actively navigate from that position, in that perspective we could also emphasize the geographic flexibility employers request. That would ensure we to a limited extent address employability from all three perspectives mentioned in model one. One obstacle we often meet is that the students seem to be taken the transversal skills for granted, and they assume that once they enter the job market every employee has developed effective collaboration skills, and the ones who has not, do not complete their educational degree. This conviction has also been reported by Trevelyan (2010), we try to mitigate this by actively addressing it in front of the students, whether it has an effect though, we don't know.

As of now, there has not been any follow up towards whether the competence profile has influenced the students' job search, we hope to examine this in the future as well. Furthermore, for future work we will try to combine all the volunteer activities students are offered in relation to their employability with this mandatory activity and provide the students a package, that makes sure everything talks together.

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Re/upskilling the agricultural labour force: Micro-credentials as innovative LLL strategy

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ABSTRACT

Industry 4.0 had a strong impact on globalization by changing the workforce and increasing access to new skills and knowledge. According to the World Economic Forum, by 2025, 50% of all employees will need reskilling due to new technology. Industry 5.0 addresses long term prospects such as sustainability, resilience and human-centricity regarding efficiency and productivity. Agriculture is the most exposed economic sector to climate change with cascade effects on agro ecosystems. Innovations in the agricultural sector are inevitable to ensure food security and social and environmental sustainability.

This paper presents two Erasmus+ projects that highlight the importance of future engineering education in the agricultural sector considering change drivers and challenges (e.g., climate change, labour market needs, digitalization, pedagogical approaches, micro-credentials). The goal is to provide holistic competence-based education that helps learners develop sustainability skills for responsible action. Therefore, we combine innovative pedagogic approaches with substantial content, to allow up/reskilling in a short period of time. We consider opportunities and limitations and how comprehensive agricultural engineering courses must be designed to be effective. We present innovative learning approaches in the realm of agricultural engineering and evaluate the efficiency of short courses (6 ECTS), micro credentials.

Analysing the experiences of several courses conducted at different European universities in past years, we can conclude that if the right pedagogic methods are paired with substantial content, up/reskilling is possible in a short period of time (6 ECTS). Main beneficiaries are agricultural professionals, who are interested in innovative, remote learning opportunities.

1 INTRODUCTION

Lifelong learning (LLL) is important for agriculture and the agricultural machinery industry to adapt to the rapidly changing technological environment (Carnoy and Luschei 2008; Atchoarena and Holmes 2005). The two sectors, like many others, are affected by massive changes, which have a constant impact on the labour market skills requirements. According to the World Economic Forum, by 2025, 50% of all employees will need reskilling in order to adopt to new technology. Industry 5.0 addresses long term prospects such as sustainability, resilience and human-centricity regarding efficiency and productivity. The fourth industrial revolution technologies are the driver for this transformation in the agricultural sector, and generally affect many spheres of life including education.

The increasing world population as well as recent political challenges and changes in production brought by climate change put an increasing demand on efficiency in the agricultural sector. Simultaneously, accelerating technological developments will provide possibilities for a range of novel tools/technologies that can be used to overcome these challenges. These new technologies, based in the digitization of processes, also known as smart farming/ smart agriculture, refer to the modern application of ICT in agriculture, enabling new practices such as precision agriculture, agricultural automation and robotics, management information systems and more.

According to the OECD study on *Automation, skills use and training*, a high level of automation is likely to occur in routine jobs with low skill and education requirements (Nedelkoska and Quintini 2018, 202:6). This implicates that the highest demand for future skills as result of changes and digital technology is in automation and machine learning. The key processes of promoting learning for sustainable transitions and developments are collaboration, engaging with whole systems applying a holistic approach, innovation in the curriculum, teacher and learning experiences, and active and participatory learning.

International partners from Sweden (SLU), Germany (TUM) and Italy (UNIBZ) formed a working group with BOKU with the aim of an international education program for Re/Up-Skilling agricultural engineering focusing on animal welfare, biodiversity, artificial intelligence, and nutrient efficiency. The goal is to provide holistic competence-based education for required skills by implementing a lifelong learning strategy for agricultural professionals with diverse education and working backgrounds coming from practical farming, agribusiness, the food industry, retail, extension service and administration, the IT sector, environmental science education, and research institutions.

This paper presents the implementation and results of two Erasmus+ strategic partnership projects: **Upskilling the Agricultural Engineering in Europe – USAGE** and **Upskilling the Agricultural Engineering in Europe Next Generation - USAGE NG**. The aim of the projects is to foster Up/Re-skilling agricultural engineering in Europe and to follow labour market requirements through the development of competence based LLL curricula and the implementation of innovative pedagogical approaches. Furthermore, with a special focus on sustainability competences development, these projects use the European sustainability competence framework, GreenComp, to review the curricula, design education programmes, and implement certification, assessment, monitoring, and evaluation.

1.1 Modularity

The concept of up/re-skilling pathways follows modularization at each partner university institution based on standards and guidelines for modules development ensuring quality assurance, implementation of innovative teaching and learning methods, analysis, and improvement. Furthermore, it is built in accordance with the recommendations on the validation of non-formal and informal learning CEDEFOP: **Assessing skills** – identification of existing skills and competences and needs for upskilling; **Tailored learning offer** – competence-based education to meet the needs in skilling; **Validation and recognition** – the acquired knowledge, skills and competences are validated and recognized.

For these purposes one of the planned deliverables was the handbook with guidelines on lifelong learning, pedagogical approaches, and validation procedures for non-formal and informal learning.

1.2 Micro credentials

Based on the European approach to micro credentials, the learning offers combine innovative pedagogic approaches (e.g., blended learning, learner centred approach) with substantial content to allow up/reskilling agricultural engineering in a short period of time. We consider opportunities and limitations and how comprehensive engineering courses must be designed to be effective micro credentials.

2 METHODOLOGY

2.1 USAGE Modularization- A competence based LLL education for up/re skilling pathways in agricultural engineering

The afore-mentioned universities developed a common approach towards LLL opportunities about Smart Farming and implemented several independent courses. In order to create a targeted offer from the universities in this growing and proliferating market, a basic demand analysis for the relevance of continuing education was carried out. According to a survey with 70 participants in Germany, Austria, and South Tyrol - agricultural producers and associations, private companies offering products and services to agricultural producers, public facilities as well as NGOs and students - the demand for LLL courses in the field of smart farming was analysed. The topic “Smart Agricultural Engineering” attracted the attention of 74% of the respondents. Out of the eight topics, the highest priority was given to "GIS&FIMS", "Logistics", "Environmental Sustainability" and "Crop Production" (see Figure 1). Furthermore, results show a corresponding interest in offers at universities and modules in the field of smart farming.

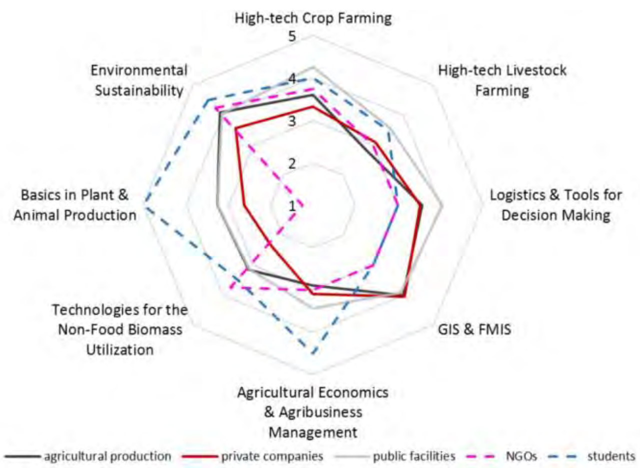

Figure 1: Level of interest in topics by organization type, measured in mean values (n=70) (Bernhardt et al. 2022, 3–4)

The concept consists of several modules that are equivalent to a current university module. This makes it possible to evaluate them similarly to a study module with points in the European Credit Transfer and Accumulation System (ECTS) and thus make them comparable (Bernhardt et al. 2022, 3–4). The continuing education program should comprise 5-6 ECTS modules. The relevant topics in smart crop farming and livestock farming are identified and learning outcomes (knowledge, skills, and competences) are prepared in compliance with the definitions for EQF level 7 (EQF – European Qualifications Framework definitions). The common language is English. The curriculum and admission requirements for each module are prepared within guidelines from each partner institution, and a local website was provided for dissemination purposes. In addition, this enables transparency of the services provided. A certificate is issued for each module that participants successfully complete. An individual module takes about 3-4 months, which corresponds to 150 working hours.

Admission to each module (course) requires a bachelor´s degree in natural resources, life sciences or technical sciences, or a degree from an advanced technical college. In individual cases also applicants without the above-mentioned degrees but with demonstrated long-standing relevant professional experience may be considered for admission to the certificate courses. This is foreseen by assessing skills through interviews between professors, the program director and candidates including LLL experts and using online examination tools. The admission criteria for the lifelong learning participants are regulated by validation procedures of non-formal and informal learning for the students with diverse education backgrounds. BOKU has developed the concept based on the European Guidelines for the Validation of Non-formal and Informal Learning.

LLL strategy for Teaching methods and learning outcomes

Following the modular approach and to meet the needs in up/re-skilling the expected target groups, the USAGE project partner SLU provided training for teachers on innovative pedagogical approaches, which are flexible and follow a learner-centred approach. It is designed to shift the focus from time-based learning to competency-based learning. Instead of being confined to a certain number of hours in the classroom, learners can progress through the program remotely if they demonstrate that they have acquired the required skills and knowledge.

The methods of student-centred learning range from personalized learning, problem solving learning, critical thinking, flipped classrooms, case-based strategies, and strategies involving small/large group discussions among others. Teachers have implemented these diverse teaching strategies to facilitate transversal and interdisciplinary learning e.g., academic knowledge meet practice, seminar group discussions, observations, and reflections. (Norman and Spohrer 1996, 26)

The consortium partners in collaboration with project industry partners have developed the modules with a focus on “Smart Farming” based on a holistic view on digitally transformed farms and agricultural data mining. A range of e-learning activities (e.g., synchronous/asynchronous, expositive, application, and collaborative methods) support the achievement of the learning objectives. Therefore, different types of lectures and seminars were taken into consideration and a research based Agri-Tech LAB from UNIBZ for the practical studies has been implemented. The focus was on upskilling for the use of technology applications in soil management, seeding management, water management, fertilizer management, grass yield management, harvesting and production as far as product quality assessment in the fields of crop, fruit and animal production. Therefore, students gathered knowledge, skills, and competences in the application of intelligent information and communication technology systems such as sensors, IoT, GIS, cloud-based processes, machine learning, artificial intelligence, networking to the farming system such as crop cultivation, livestock farming and fruit production. This lead also to the acquisition of transversal skills such as critical thinking ability for applying precision agriculture technologies for decision making.

On the blended learning in the customized and certificate course “Smart Farming and IoT in Agriculture”: TUM implemented the virtual kick-off meeting and team building; all participants had four days of face-to-face learning with practical exercises on tractors and drones at the Campus TUM (see Figure 2). Furthermore, the two following field trips were organised 1. “A Smart Farmer´s Perspective on the Future of Agriculture – at the geo-konzept GmbH company and 2. “A Global Perspective on the Digital Transformation of Agriculture – at BayWa AG”. For the e-learning asynchronous part, TUM provided videos from TUM-streaming servers and guided do-it-yourself@home by using the MOODLE platform. For the practical exercises, TUM supplied participants with the microelectronic skiz Raspberry Pi and Arduino. Certificates are earned after successfully completing a final exam, presentations of participants’ use-cases.

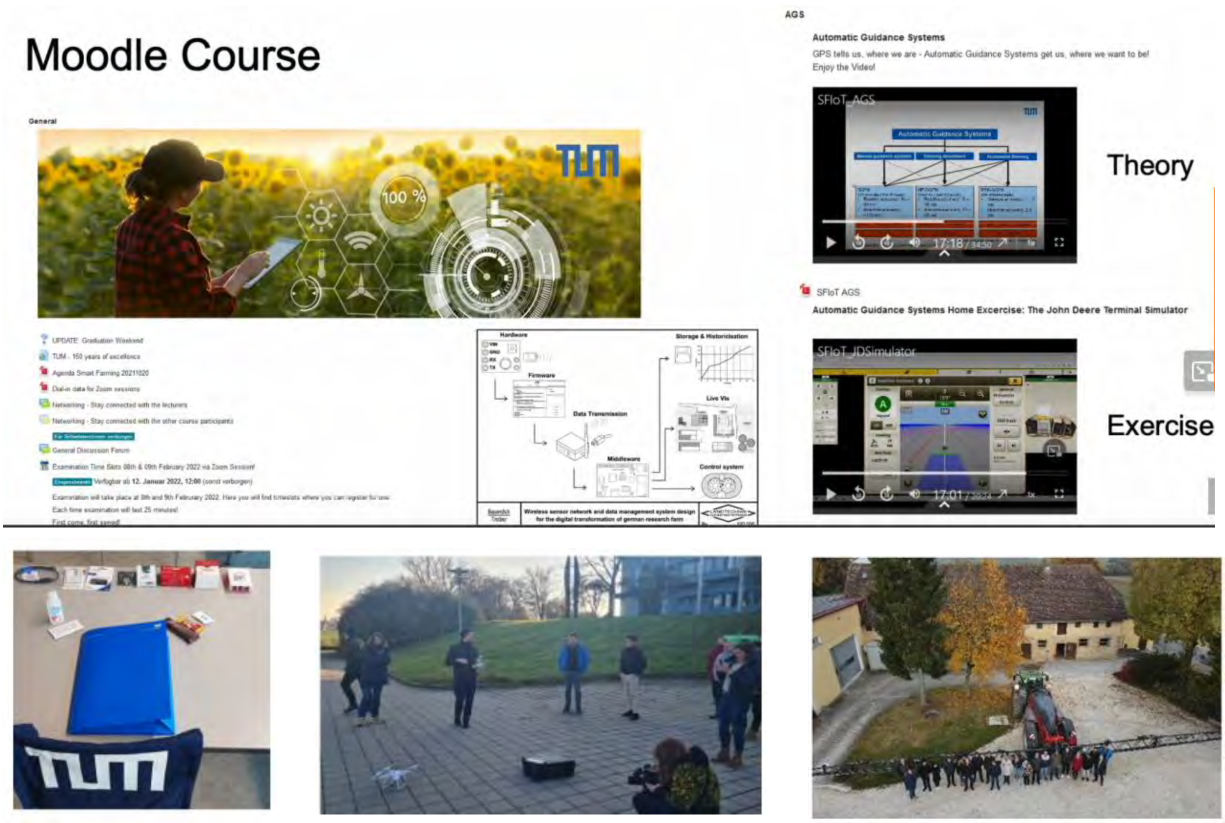

Figure 2: Blended learning in the TUM course “Smart Farming and IoT in Agriculture”

2.2 Section 2 Micro credentials development as innovative LLL strategy – USAGE NG

The objective of the USAGE NG project is to make learning paths more flexible at different stages of life by increasing modularity of studies and providing learners micro credentials. Therefore, we examined the role of micro credentials in the agricultural sector and assessed which micro credentials are relevant. What is the university strategy for micro credentials development and what are the main challenges? What are the added values: better job opportunities, reskilling, involvement of industry in education, or personal motivation? We apply desktop research as the qualitative method that contains elements of thematic analysis, secondary data analysis, and a bottom-up approach. This research is related to the collection, review, and analysis of data on micro credentials in agricultural engineering. We will provide a post survey among graduates, a digital-based-review of acquired new skills at work regarding employability enhancement.

USAGE NG is using these findings on micro-credentials as a tool for flexible and extra-curricular learning offers that address competences that go beyond the typical core curricula. The development of micro-credentials as a basis serves modules development and applied innovative pedagogic approaches in the USAGE project. *This experience will be integrated into the micro credentials - competence oriented short courses (1-15 ECTS) with the focus on skills and how they will be put into actual practice and how they will be reflected in the evidence*. (Maina et al. 2022, 12–15)

Based on the European approach to micro-credentials, our learning offers merge different perspectives of the various backgrounds of learners and teachers and are linked with a distinct, targeted learning experience with clearly defined learning outcomes that are assessed against transparent standards. The main objective of the European approach to micro-credentials is to facilitate their validation, recognition, and portability. Therefore, we implement four phases of validation procedures: Identification, Documentation, Assessment and Certification based on the CEDEFOP guidelines adopted for micro credentials (CEDEFOP 2015, chap. 3). We are considering who the validation process responds to, and the interests of the target groups; taking serious care about the target guidance and counselling services; choosing the right tools and instruments for the identification, documentation, and assessment of learning. The validation process will be linked to national qualifications frameworks of the partners as well to the European Qualifications Framework taking into account that the outcomes of validation refer to the same or equivalent standards as those used for formal education.

3 RESULTS

3.1 Analysis

In the meantime, at partners institutions a wide variety of course concepts have been developed and implemented in two rounds during the project lifetime. A key aspect resulting from the experience of the individual courses is the further adjustment of the educational offer. To this end, surveys were conducted among course/module/micro credential graduates. The qualitative analysis follows content analysis based on feedback provided by the survey to evaluate and to improve the content, to determine graduate preferences, and setting the direction for future developments. A teacher and teaching methods evaluation was also included. Two out of five respondents replied that most of their expectations regarding the course were satisfied; three respondents replied that some of their expectations were satisfied.

Due to the need and request for the courses to take place outside of normal working hours, one course was organized on two dates as a weekend course from Thursday evening to Sunday. The learning was rather intense, however, reflection time on the learning was limited. Another course was, also because of the COVID-19 pandemic, a complete online offer with prepared learning units and additional online discussion groups. Although the learning material was conveyed well, the participants missed the group exchanges. Therefore, the next course was developed considering this initial experience; two weekend dates (Friday to Sunday) are offered at the beginning and end of the course with special emphasis on group cooperation with excursions and group work. In between, prepared teaching and practice sessions are offered for participants to work on independently. For communication there is a weekly online meeting where the progress of the projects is discussed. Thus, a good balance between communication and teaching content is achieved.

Another interesting aspect is the group composition of the individual courses. Employees of agricultural companies use the course to reach the next level of development in their companies, whereas doctoral students - in or after the final phase of their doctorate - are interested in further orientation. International master's students have similar interests; some of these students had already completed extensive studies abroad and came to Europe to pursue a master's degree. For managers from agricultural engineering companies, who often had a very high level of knowledge in the field of smart farming, knowledge transfer plays only a subordinate role in the course as they are much more interested in making new contacts with the other participants and talking to the lecturers at the same level.

The below feedback (Figure 3) on the course Smart Farming and IoT in Agriculture – TUM is consistently positive. The videos and exercises were particularly well received; so was the overall course organisation and related communications. Although there are minor variances on the responses related to questions on the online elements, the overall level of satisfaction is very high.

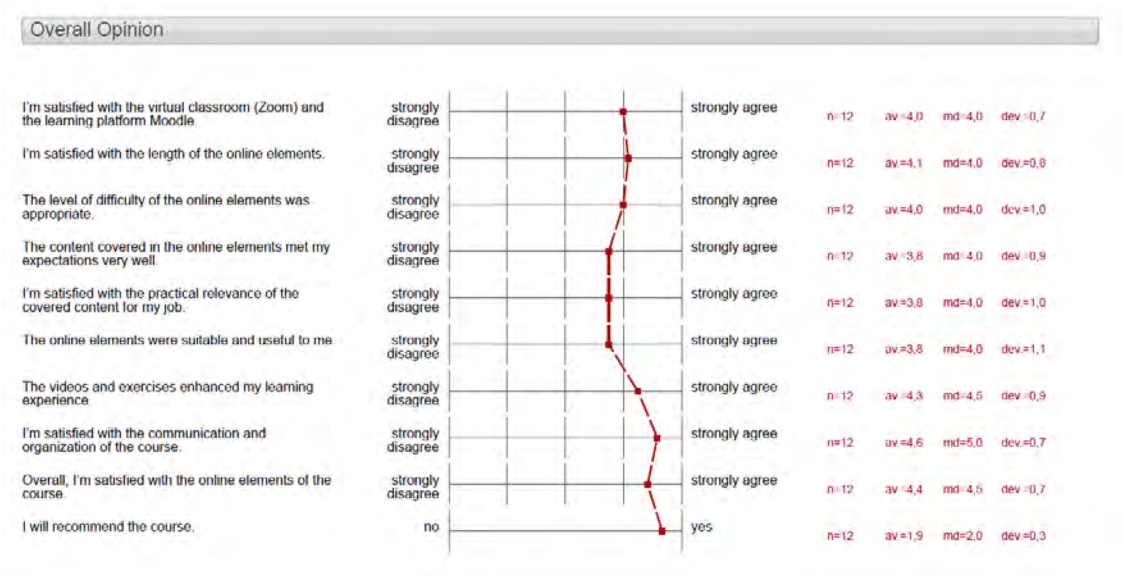

Figure 3: Smart Farming and IoT in Agriculture Online Sessions (n=12) feedback

Local language is the preferred graduate language which is included in the second round of courses development. An important aspect for some participants was that the courses are included in the ECTS through the universities, which makes it possible to apply the work done in the course to other continuing education programs based on it. With the full costs of the courses between EUR 2.000 and 5.000, the survey revealed that these prices lie generally at the upper edge of the participants' willingness or ability to pay. Here the universities must consider which service they want to offer for which price. This is still an unfamiliar area for many European universities, and it has become clear in the course development and implementation that this cannot be done on the side by a professorship or the university. The courses need to be marketed at full cost on the free market and they must therefore also offer the generally required service. Hence, special organizational units with appropriate equipment must be created to develop this additional offer sustainably for the universities in the long run. It becomes clear that for LLL special offers are necessary, which differ from the normal teaching concepts of universities, and which are specially aligned to the target groups (Bernhardt et al. 2022, 4–5).

3.2 Conclusions

The analysis of the experiences of several LLL courses conducted in past years shows that if the right pedagogic methods are paired with substantial content, e.g., smart agriculture with a learner centred approach, up/reskilling is possible in a short period of time (6 ECTS). Furthermore, pedagogical innovations such as micro credentials enhance the visibility, transparency and trustability of new skills and enable a better understanding of the collaboration between higher education institutions and the agricultural business sector. Results also show that students have increased the awareness of their employability skills and of the labour market expectations. Micro credentials create a basis for transdisciplinary cooperation and for collaboratively handling professional and societal challenges.

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DEFINING A EUROPEAN ENGINEER PROFILE WITHIN A EUROPEAN UNIVERSITY ALLIANCE

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ABSTRACT

The world needs more engineers and Europe provides a rich and diverse environment to train them, including shared values of sustainability and interculturalism. In this paper we attempt to build a profile for a “European engineer” based on skills and competences acquired in a European University Alliance centred around engineering education (EELISA, European Engineering Learning Innovation Alliance). We carried out an on-line survey for students and staff of partner universities as well as nine in-depth interviews (50 min) with relevante stakeholders. The questions included in the survey are described as well as general results from 75 respondents. The overall results from the in-depth interviews are also presented and discussed within the framework of the training concepts also promoted by international associations, including SEFI. Finally, we use our findings to suggest four conceptual fields for a European engineer profile: 1) Scientific and theoretical knowledge including digital skills, 2) Addressing sustainability, 3) Interculturalism: an engineer embracing the European project, and 4) Business and communication skills: practical and applied knowledge.

1 INTRODUCTION

The world needs more engineers and Europe provides a rich and diverse environment to train them. That training can involve mastering technical disciplines and science-based processes and phenomena, as well as softer skills to help integrate technical, environmental, and social dimensions. Engineers face new challenges in a global society where multiple professional practices can be required to tackle global issues, while respecting local specificities. All this requires mastering a new skill set or gamut of competences that are not always clearly defined.

Most universities provide excellent scientific and technical knowledge to train different types of engineers, but there is more debate about how to educate students in more transversal skills, such as certain values like ethics, sustainability and interculturalism, so as to train them to be able to manage and innovate once in front of complex problems in their professional practice. Within the context of the European Universities Initiative (European University Alliances) and increasing collaboration with industry, it has become increasingly important to define and to be able to compare university studies in terms of an overall engineering profile, as commented by other authors. For example, Magarian and Seering (2021) indicate that engineers obtain a unifying work attribute called “design responsibility”, which includes product efficacy and safety through governance of new or existing designs. Zhu et al. (2021) formalize very precisely the skills involved for engineers in a Chinese industrial context such as sensemaking, relating, visioning, and inventing, which go far beyond technical skills in engineering. Diaz-Lantada and Nuñez (2021) recognize the importance of basic disciplines of science and technology and Diaz Lantada et al. (2016) underline that theoretical focus on basic science and technology is a required first step and must be detailed in depth, to then be able to focus on more applied activities. Indeed, a thorough knowledge of the basics will also allow students to be more flexible in their applications later on.

In terms of future joint degrees, where students will move from their home institution to study in one or more different EU countries, several universities must agree on basic requisites for more fundamental and more transversal skills to be able to create and compare study programs. A profile or definition of course requirements for different degrees may be fairly straight forward, but less work has been done to help define the requirements for more transversal skills.

In this study, we aimed to develop a profile for a European engineer along those lines. This can help to create joint degrees and the framework can be used to attract and host more international students, improving prestige and moving towards a European identity. The idea is for the profile to include the attributes, skills, lived experience and attitudes that make a graduate in engineering most adapted to the needs of the workplace, to help students be more prepared to conduct his/her professional activity within a sphere of certain values and to seek opportunities for innovation and responsivements to societal, economic and environmental challenges.

2 METHODOLOGY

Here we summarize efforts within Work Package 2 of the EELISA Erasmus+ project to define an engineer profile with the EELISA Alliance, based on the results from an on-line survey and in-depth interviews with relevant stakeholders.

2.1 On-line survey

This survey consisted of five general questions which could be answered online. It was sent to the nine partner universities of EELISA (Budapest University of Technology & Economics, Ecole des Ponts ParisTech, University of Erlangen Nuremberg, Istanbul Technical University, Scuola Normale Superiore di Pisa, Scuola Superiore Sant'Anna, Polytechnic University of Bucharest, Universite PSL, and Universidad Politecnica de Madrid). The first three questions were related to the job and field of work of the person being questioned, and whether they were from a university in the EELISA alliance. The following two questions (questions 4, 5) are summarized in Table 1.

Table 1. List of questions 4 and 5 in the survey sent to EELISA partners (students and staff).

4. Reflection on the profile of a European engineer.	
	a) Please rate the interest of a European engineering degree in addition to a national engineering degree* (rate low interest-1 to extremely interesting-10)
	b) Please rate the interest of a European engineering degree instead of a national engineering degree (rate low interest-1 to extremely interesting-10)
	c) What should be the minimum scientific and technical learning outcomes common to all engineering disciplines? (rate low interest-1 to extremely interesting-10)
	c.1. To analyze and synthesize complex problems by mastering scientific fields c.2. To design, implement and validate innovative methods, products and solutions c.3. To carry out research activities and to set up experimental devices c.4. To be adaptable to current and future real-life challenges c.5. Other (please specify):

	d) What are the required learning outcomes related to social and environmental issues of an engineering degree? (rate low interest-1 to extremely interesting-10)
	d.1. Developing human-centred view of solutions d.2. Knowledge of ethical responsibilities d.3. Knowledge of health, safety and diversity issues d.4. Consideration of the societal and environmental consequences of developed solutions (products/devices/processes, etc)
	e) What are the required learning outcomes related to management and leadership skills of an engineering degree? (rate low interest-1 to extremely interesting-10)
	e.1. Project management e.2. Innovation and creativity e.3. Ability to find compromises e.4. Recognizing the value of other (foreign) systems and approaches e.5. Curiosity and pragmatism (not self-centred) e.6. Team management, practice collaborative and remote work e.7. To be able to communicate with specialists and non-specialists
	f) What are important intercultural skills that can be taught to strengthen the European dimension of the of engineering education? (interest-1 to extremely interesting-10)
	f.1. Knowledge of histories and cultures of other countries f.2. Accept different abilities to work in relation to different nationalities, societies and ways of life f.3. Mastery of one or several foreign languages f.4. Knowledge of systems of thought of the societies f.5. Knowledge of social, political and economics frameworks of the societies
	g) What are the aspirations of students in terms of professional endeavors in your point of view? (max 5 keywords, separated by commas)
	h) Are there other areas or learning outcomes you would like to mention? (max 750 characters)
5. Here is a list of EUR-ACE © learning outcomes which are recommended to train an engineer. Could you provide a specific innovative teaching method you think of, or a best practice you have in mind to obtain these learning outcomes?	
	a) Knowledge and understanding b) Engineering analysis c) Engineering Design d) Investigations e) Engineering Practice f) Making Judgements g) Communication and Team-working h) Lifelong Learning

2.2 In depth interviews

A second survey consisted in hiring a consultancy firm to interview nine European leaders working at companies in Europe. Two main questions were asked, 1) What characteristics should the engineer of the future have? 2) What is the set of skills that he/she should develop to face a professional development for being a leader. The people questioned included 9 leaders/senior level management positions in leading companies and organizations (men and women) in 5 different countries which host the universities within the EELISA alliance (France, Germany, Romania, Hungary and Spain) and respondents based outside Europe with international functions. Each interview lasted 50 minutes and was open to spontaneous discourse.

3 RESULTS

3.1 On-line questionnaire

A total of 75 people participated in the web survey, 16% of which were not staff or students from the EELISA universities. Approximately 37% were professors or research staff from universities and more than half were students (55%). Most of the respondents felt an interest in obtaining a European degree, although students were less keen on obtaining a European engineering degree instead of a national one, underlining that the view is more of an additional degree than a substitution of local degrees. Regarding the learning outcomes of scientific and technical knowledge, most respondents (above 70%) mentioned being adaptable to current and future real-life changes and being able to analyse and synthesize complex problems, and design, implement and validate innovative methods, products and solutions.

Related to learning outcomes on social and environmental issues (question 4d), respondents were more interested in outcomes related to "ethical responsibilities" and "societal and environmental consequences of developed solutions". Regarding business and management skills (question 4e), respondents mostly underlined the ability to communicate (with specialists and non-specialists), team working skills, as well as curiosity and pragmatism. Responses about intercultural skills (question 4f) were more varied but mostly centred around the ability to work with different nationalities and master several languages.

When asked about what types of innovative teaching methods could be used for different learning outcomes based on the EURACE accreditation system (Question 5), the responses were also quite varied but the word cloud analysis suggests the following pairing: knowledge and understanding (practise), engineer design (solutions), research (studies), engineering practise (real projects), making judgements (learning by projects), communication and team-working (team work).

3.2 In depth interviews

The results from the in-depth interviews of nine senior managers in leading European companies suggest that the specialized knowledge of current engineer graduates in Europe is excellent and should be maintained at a high level, including basic science skills. Most respondents found it difficult to predict the qualities required of engineers in the future, mostly due to uncertainties related to technological change. On the other hand, for the future they suggested improvements in the following fields:

Sustainability

According to the respondents, engineers should have the knowledge and the mentality needed to overcome different sustainability challenges. Younger generations seem well prepared. These were not seen as primary skills but as awareness necessary to motivate engineers to excel at their work. This could be further promoted by increased cooperation between companies and students during their studies, on state-of-the-art technological solutions to sustainability issues.

Interculturalism and inclusiveness

In general, respondents thought that European students have had some exposure to other countries and cultures, having studied abroad through different mobility schemes, but in some countries (e.g., France and Spain), the level of English could be improved. Regarding inclusiveness, for some companies, it is difficult to reach a gender balance but the incorporation of women is promoted and several interviewees mentioned that including more women in their workforce can create better working conditions.

Business and social skills

Respondents concluded that current and future engineers require stronger training in management skills, including human interaction/communication, entrepreneurship, finance and leadership. Although these skills can be acquired on the job, the overall feeling is that more of these subjects could be included in the degree programs. Engineers should be better trained to understand decision making in a company, under uncertain situations and to be prepared to react quickly about adopting new technologies. A better knowledge in economic viability (handling finance) of project would be welcome. When managing a project, engineers should also consider how the end client will use the proposed solution.

Social and communication skills could be improved by considering the knowledge of other people (inside a company) and by improving empathy. Engineers, especially those in leadership positions, need to know how to adapt their communication with stakeholders (higher authorities, other companies, social communities). This goes hand in hand with a good general culture in various fields (economic, political, cultural, etc.).

4 DISCUSSION

Within the overall framework of a degree program, which includes both a Bachelor and Master's degree in Engineering, knowledge of basic engineering and scientific skills is essential. These technical and knowledge-based skills involve understanding the importance of measurement (including data acquisition, literacy, analysis and management), in real or simulated contexts, and an analysis of how different equipment has evolved over the years, thanks to applied research. As confirmed in the general outline of the Learning Outcomes by ENAEE [5], engineers must have, first and foremost, "a thorough knowledge and understanding of mathematics and other basic sciences inherent to their engineering specialty". Acquiring these core skills is essential to support flexibility, adaptability to changing technologies and life-long learning. However, given the current ecological context, the applications and developments of new techniques need be compatible with planet boundaries and ecological limits [6]. They should also be compatible with democratically established societal goals.

Because these challenges (to which we can add the digital revolution) involve complex situations, uncertainties and multiple stakeholders, future engineers also need to acquire a series of skills revolving around the concepts of cooperation, innovation and entrepreneurship in an inclusive environment. Again, referring to the Learning Outcomes by the ENAEE, engineers must be able to “make judgements, communicate and work in teams”. They should be able to use different methods to communicate their conclusions, clearly and unambiguously, and the logical foundations supporting them, to specialized and non-specialized audiences, in national and international contexts. According to the Conference of Deans of French Schools of Engineering [7], future engineers should be active team-members and contributors to innovation, with competences in management skills, economics and finance, working in multiple disciplines and with a spirit of interculturality to propose innovative solutions.

4.1 A European engineer profile

Taking into consideration the results from the survey and in-depth interviews, we propose an outline for a European Engineer Profile (EEP) that includes a set of skills encompassing scientific, technical and more relational outcomes, within the European context of diversity and mobility. The EELISA-EEP can help to provide a scaffolding for the Learning Outcomes for a future joint degree, as well as ideas for the EELISA Supplement and Credentials. The EELISA-EEP is based on pre-existing frameworks such as the EUR-ACE® Framework Standards and Guidelines (November 2021) and the Washington Accord Graduate Attribute Profile (Nov 2021), but with additions emphasizing the importance of mobility and the European dimension. In that light, most international standards for engineer profiles underline the importance of key concepts such as understanding, practice, design, research, knowledge, methods and complexity. Most frameworks can also be divided into hard skills and transversal ones, with some emphasis on practical knowledge, but few point out the utility of mobility/diversity during the degree to help promote learning. We propose that the EELISA-EEP includes four conceptual fields within its framework.

Scientific, theoretical knowledge and digital skills

This part of the profile involves core skills or theory-based understanding of the basic sciences in each field of engineering, for example mathematics, computing, and their use to develop products, processes and systems. Students are exposed to theoretical problems and the formulation of possible solutions based on engineering fundamentals, in a design framework. Here access to research methodologies and relevant literature is key to help evaluate the data or processes using state of the art methods. Excellent scientific knowledge should be the backbone of the European engineer profile.

Addressing sustainability

European engineers will need to understand how the techniques they develop are compatible with the depletion of natural resources and avoid irreversible situations. Especially, they will need to consider the entire life cycle of products and services they design and produce. This implies a critical and thorough analysis of the socio-environmental risks pertaining to the development of new technologies.

Interculturalism: an engineer embracing the European project

Just as practical learning may help to understand engineering fundamentals, adding mobility in a degree program can help facilitate understanding and incorporating soft skills on a personal level. By being exposed to different professors, university environments and cultures, students will become more aware of different societal issues, ethical problems and cultural dispositions. Mobility also provides a means to being exposed to a working environment in a different country via internships. The ambition with mobility in EELISA is to go beyond an exposure to different cultures and different ways of thinking. The core of this project is to nurture an atmosphere of cooperation and common values around cohorts of students that will embrace the European engineer vision of EELISA and develop across geographies and over time a shared vision of Europe and its values.

Business and communication skills: Practical and applied knowledge

Engineers should be able to work with theories, concepts, materials, equipment and tools outside the classroom to apply problem solving techniques. This will also expose them to economic, organisational and managerial issues, and enhance a critical sense and judgment about the application of different solutions. They need to adopt a user-centric approach to gather societal expectations with technological ambitions. There are many ways to ensure students engage in work to acquire the expected expertise of engineering analysis, design and practice, including problem-based learning.

Given the uncertainty and complexity of real world situations, while applying the theoretical and practical knowledge they obtained, engineers will need to consider social objectives, and ethical responsibilities in addition to sustainability issues. Because they are at the interface between science, techniques and society, they will also require training related to communication skills, decision-making and independent learning to better integrate the views of multiple stakeholders into their decision and creative processes. These skills are best learnt in real contexts, in which students, having acquired basic principles, put them into practice in actual multi-lingual, multi-cultural and inter-disciplinary contexts. The complexity of decisions they will need to tackle involves a reflexive thinking posture on their own practice. This analytical thinking can feed back into their professional actions and further improve common knowledge. Given the fast evolving technological and societal environment, the European engineer needs to adopt a position of continuous learning that will maintain its ability to address societal challenges over time and to manage younger collaborators within its firms.

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Unlocking Deeper Insights: A Qualitative Approach to Evaluating STEM Outreach in Engineering Education

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ABSTRACT

Much previous research and evaluation has been conducted of STEM Outreach activities in schools using quantitative approaches. Surveys in particular are popular as they are low-cost and time-saving. However, quantitative methods are limited in that they do not generally generate deeper insights into students' experiences in STEM; usually lacking rich detail about the context and complexity of the data being analysed. Hence, this paper proposes a different approach to evaluating STEM outreach: a unique multi-method, qualitative approach.

Starting with the Research Question "How to qualitatively evaluate STEM outreach in Engineering Education?", this paper is grounded in ongoing doctoral research that addresses a substantial gap in knowledge pertaining to how STEM outreach is evaluated. This methodological gap became apparent during the Pandemic when STEM activities were offered, yet there was not a robust way of evaluating the children's experiences. This paper outlines a qualitative research design that employs a Multiple Case Study approach with Grounded Theory. It argues that a qualitative design can be used to acquire an in-depth understanding of data that is both insightful and unique. The paper adds to knowledge in the area of methodological design within engineering education research, and such data can then be used to inform the provision of future STEM outreach. Furthermore, the researcher's ongoing fieldwork experience is also reflected to identify the unique challenges in the methodology execution. The insights on how to address these challenges can support academics in Engineering Education Community to engage in qualitative research.

1 INTRODUCTION

This paper is based on ongoing doctoral research in STEM outreach evaluation, reflecting on a qualitative research project in the West Midlands area of the United Kingdom. The research focuses on the evaluation of engineering outreach activities from the Lord Bhattacharyya Engineering Education Programme (LBEEP), which is designed for secondary students aged from 11 to 18 years old.

STEM outreach has been widely acknowledged as a beneficial complement to conventional in-class learning, as it exposes students to real-world settings and enhances their interest and attitudes towards STEM subjects and careers (Vennix et al. 2018). However, there is a lack of evidence of the actual effect of STEM outreach in increasing the number of young people studying engineering subjects at both higher and further education institutions, despite considerable efforts by the government, educators, and other stakeholders (Morgan et al. 2016). In recognising this, the research seeks to address the challenges faced by the evaluation of STEM outreach and to develop a qualitative methodology design as one of the possible solutions.

Current research on STEM outreach evaluation is predominantly quantitative, with surveys being the most commonly used method (Pearson et al. 2022), with 87% of organizations evaluating their outreach and 98% of these evaluations involving the survey as a research method (Morgan et al. 2016). The extent and nature of evaluation methods depend on the resources available to the outreach providers or education institutions, which may be limited. Hence, such kind of quantitative survey is widely used due to its advantages of low cost, time-saving, and easy-to-use features in the short-term STEM interventions' evaluation. However, they may not provide a rich description of complicated outreach settings or illuminate students' experiences (Leydens et al. 2004). Furthermore, the lack of a standard evaluation framework for STEM outreach interventions makes it difficult to ensure comparable quality assurance across a wide range of activities, which are significant to sustainable and scalable outreach evaluation.

To address these challenges, this work-in-progress proposes a qualitative approach to evaluate STEM outreach in engineering education. Thus, the research question is "How to qualitatively evaluate STEM outreach in Engineering Education?", to develop a qualitative design for STEM outreach evaluation to gain an in-depth understanding of students' experiences. This can help to generate a theoretical evaluation framework as a final deliverable. Therefore, the paper presents a new methodological approach and then follows a reflection on the methodology implementation, in order to propose recommendations on the experiences of data collection.

2 METHODOLOGICAL CHALLENGES IN STEM OUTREACH EVALUATION

While many STEM outreach initiatives claim to be helpful, few appear to provide convincing evaluation outcomes (Bogue et al. 2013). Potential reasons for this are the lack of a systematic evaluation framework and missing the individual participants' experience during the evaluation. This section discusses these two emergent methodological challenges when evaluating STEM outreach programmes.

2.1 Lack of the outreach evaluation framework

Frameworks for discussing and categorising STEM outreach activities are essential but significantly lacking (Miranda and Hermann 2010). The diversity of participants and outreach themes in outreach evaluation reflects the efforts of establishing evaluation measures in isolation, rather than as a collective evaluation framework applied across all outreach programmes on offer. Due to methodological obstacles, as well as financial and resource constraints, a standard framework has not been generated to evaluate STEM outreach interventions due to varied contexts, scopes, and aims. The lack of a standard framework also challenging to propose meaningful and credible data collection questions to probe the value of the outreach. To fill in this gap, developing a general assessment framework across diverse STEM outreach activities and comparing the effect of different STEM outreach activities is a significant opportunity for contribution.

2.2 Collecting data on individual experiences

Quantitative evaluation work using surveys is popular in STEM outreach assessment, especially in the evaluation of short-term initiatives (Saw et al. 2019). One of the reasons is the utilisation of qualitative methods can increase the complexity of the research design and data collection process, which may require additional resources and time to manage effectively.

However, relying on the survey to quantitatively evaluate the STEM outreach has limitations in obtaining a comprehensive understanding of the outreach impact. Firstly, surveys aim to generalise findings from groups rather than individuals, which may lead to ignoring the nuanced difference between a student's outreach experience versus others (Hazari et al. 2020). For example, some surveys collect data on attendance and satisfaction to measure outreach success (Felix et al. 2004; Sadler et al. 2018), as an indicator of students' interest and engagement in STEM outreach. Yet the survey results presented in numbers showing the group level success thus may not capture individual changes in knowledge, skills, attitudes, or the longer-term impact of the programme on their educational or career paths. Therefore, a promising alternative qualitative approach has its advantages in capturing the individual experiences of attending these STEM outreach, hearing their voices and enhancing the understanding of the outreach effectiveness (Demetry et al. 2009; Prieto-Rodriguez et al. 2020).

Moreover, the participants' experience of completing a survey may also impact the accuracy of the responses. Particularly, young students may have difficulty understanding certain survey questions or terms, leading to inaccurate or incomplete responses (Lewis 2011; Williams and Rudge 2016). This can be due to written language barriers, lack of familiarity with STEM education terms, or difficulty in articulating their thoughts. As a result, the data collected in a survey may not accurately represent the students' actual outreach experiences and attitudes towards STEM.

Considering the limitations of the prevailing quantitative approach in STEM outreach evaluation, more qualitative research is required to ensure a comprehensive and accurate assessment of the effectiveness of STEM outreach programmes. Hence, This research proposes a longitudinal evaluation of LBEEP's impact on students' attitudes towards STEM careers through a robust qualitative multiple-methods design. Multiple Case Studies, Grounded Theory and relative methods are applied to contribute to developing an effective outreach evaluation framework that can be used by educators and researchers to assess the impact of their STEM outreach programmes.

3 QUALITATIVE METHODOLOGY DESIGN FOR OUTREACH EVALUATION

In regards to the lacking a qualitative approach in the STEM outreach evaluation, this paper presents a qualitative methodology based upon Multiple Case Study Research and utilising an analytical approach based upon Grounded Theory and related research methods. Case Study Research provides the means with which to investigate the effectiveness of engineering outreach programs in enhancing or improving learning and teaching. Adopting an approach based on Grounded Theory will allow the researcher to generate new theoretical insights; this is particularly important when examining under-researched areas such as STEM outreach evaluation (Case and Light 2011). Using a Multiple Case-Study approach means that the theory generated will allow a variety of situations to be analysed from the research participants' perspective; allowing a richness and depth of data in which each emerging concept and sub-concept is examined in detail from several angles (Alzaanin 2020). Therefore, this paper adds to current debates by critically discussing how a rigorous evaluation of STEM outreach may be achieved.

To achieve the triangulation in qualitative research, multiple sources of data will be collected as listed below, including observation, focus groups with students, and interviews with adult participants (teachers, school governors, professional bodies and industry employers), to evaluate the performance of STEM outreach.

1) Non-participant observations are being used to critically study students' experience in STEM outreach on-site in schools. This involves using an observational framework to closely record how students interact with the learning environment; noting particularly how students go about solving STEM education problems through interactions with instructors and teamwork with peers. The observational data collected from students will be written down on a handwritten framework in real-time.
2) Focus groups with students are being undertaken to investigate students' learning styles in STEM subjects. Additionally, the interviews explore the students' perceptions of the transition between education stages whilst also touching on the potential for further engagement in STEM careers.
3) Semi-structured interviews with adult stakeholders such as teachers and industry employers are conducted to explore the emergent data from the focus groups and interviews whilst also providing the means for cross-verification of students' data.

The observational data will undergo analysis employing Symbolic Interactionist techniques. Symbolic Interactionism, a theoretical perspective within sociology, offers valuable insights into the dynamics and symbolic meanings embedded within social interactions (Teo and Osborne 2012). While all of the interview and focus group data will be digitally recorded and then transcribed verbatim before being subjected to a grounded theory analysis using initial and axial coding. Grounded Theory techniques are applied to qualitative data analysis including theoretical sampling, theoretical saturation, and qualitative coding. These data analysis techniques can ensure a comprehensive exploration of the qualitative data, enabling nuanced insights and a rich understanding of the multifaceted aspects within the research context.

4 REFLECTION ON FIELDWORK EXPERIENCE

This section will discuss initial challenges that emerged during the ongoing fieldwork and how they were addressed, including getting access to the field, unpredictable research environment, language barriers and ethical challenges. This reflection will help to facilitate gathering qualitative data with young people. on and further improvement suggestions are also proposed for sharing best practices with the Engineering Education Community.

4.1 Get access to the field

Gaining access to the field and building relationships with school gatekeepers presents significant challenges for a longitudinal research project on STEM outreach evaluation. School teachers or programme coordinators usually played the gatekeepers by controlling access to student participants, outreach stakeholders and other resources needed by the qualitative researcher (Harger and Quintela 2017). Access issues are made considerably more challenging when it comes to research involving children who are unable to give their consent.

To address significant challenges of access, a solution is to establish rapport with school gatekeepers through efficient communication. For example, the researcher met with school gatekeepers online or in-person to understand their concerns and priorities and gain insight into the school's context (i.e. Local environment, community engagement, student population, academic performance, STEM strategy, management and governance) prior to the formal data collection. During these meetings, the researcher provided clear and transparent information about the research, including data collection techniques to demonstrate ethical research practices and build trust. It is crucial to respect the gatekeepers' authority regarding access to resources and address any concerns they may have.

It is also essential to highlight the benefits of the research to the school gatekeepers in order to encourage their involvement. This can be done by emphasizing how the research can contribute to improving the STEM skills and career aspirations of the students and sharing the information on available outreach resources and educational partners to support the school.

In response to difficulties in accessing the research field, another solution is to adjust the methodological design. For instance, the case units were reselected based on schools' level of engagement in LBEEP. Another example is in cases of a stakeholder who provided limited access, the researcher may remove them from the sample. These adjustments facilitated a more targeted and effective data collection process despite the challenges faced. However, it is important to note that such methodological adjustments may require additional work thus impede the research progress, and may potentially introduce new biases due to missing important perspectives from excluded participants. Therefore, it is recommended that researchers approach such adjustments with resilience and flexibility, continually monitoring and adapting the methodology as needed to ensure the trustworthiness of the research.

4.2 Unpredictable research environment

To ensure the safety of children involved in the research, data collection was conducted during school hours and within the school premises. However, conducting research with children and in school environments is often unpredictable (Harris et al. 2015), which can necessitate adaptability, quick response and decision-making in order to ensure successful data collection.

Taking one student's temporary absence, for example, can undermine the quality of a planned 3-student focus group. In this circumstance, the researcher needs to make decisions quickly about whether to conduct interviews with 2 available students in this group. However, the data collected in this way may not be able to gather the same level of insights, opinions and dynamics as they would have in a 3-student focus group, where data can be rich and varied in a larger group (Gibson 2012). Hence, the researcher attempted to integrate these two students with another 3-student focus group, which expanded the number of participants in one focus group. While maintaining interaction within the group, this merging may result in a lack of focus during group discussions due to limited time. Additionally, the lack of cohesion, when compared with focus group data from other schools, may potentially impact the quality of the collected data.

This unpredictable challenge can influence the research by potentially changing the research design, affecting the data quality, and thus impacting the ability to draw meaningful conclusions and implications from the data. To address the challenges, recruiting students up to or slightly over the participant number upper limit for individual research activity will be helpful to ensure the successful implementation of the research activities. The researcher can also expand the number of research sessions to ensure enough data is being gathered even if some participants are absent. It is important to carefully consider the potential implications of any changes to the research design so that the data collected remains valid and reliable.

Another significant challenge encountered during data collection is the unpredictable behaviour exhibited by children, particularly those at younger ages. Behavioural issues of these children may hinder their learning STEM knowledge and skills, and also distract other students thus diminishing their engagement in the STEM outreach and research activities. Therefore, to mitigate these challenges and maintain a safe research environment, it is necessary to have at least one teacher present during the data collection process. The teacher's presence also provides support in addressing any unforeseen circumstances that may arise in research to ensure the safety and well-being of both the children and the researcher are prioritized. As a recommendation for practice, it is essential for researchers conducting studies involving children, particularly in school settings, to collaborate closely with teachers or school staff since their involvement can significantly contribute to creating a controlled and safe environment during data collection.

4.3 Language barriers

One challenge encountered by the researcher pertains to language barriers when communicating with students and stakeholders from diverse backgrounds, particularly for the researcher using English as a second language. To address this challenge, the researcher tailors the research protocols according to the specific needs of different participant groups. For example, the researcher utilized more accessible and child-friendly language, such as referring to "extra-curricular activities" instead of "outreach" for children participants. To ensure accessibility and avoid jargon or complex terms that may impede understanding, both student and adult versions of the research protocols were pilot tested. These adaptations aimed to align the language with the participants' developmental level, ensure their comprehension, foster participation and obtain accurate responses.

As a recommendation for practice, it is crucial for researchers to adapt their language and communication strategies to the specific needs and backgrounds of the participants (Einarsdóttir 2007). This approach promotes effective communication, improves participant engagement, and ensures that research findings accurately reflect the perspectives and experiences of the participants. Additionally, the utilization of qualitative research methods, which allow for interaction and clarification, played a vital role in enhancing data quality and facilitating a more comprehensive understanding of the research topic. These methods provided opportunities for participants to seek clarification on points they did not fully grasp, a unique advantage over survey-based approaches that lack interaction opportunities.

4.4 Ethical challenges

This research involved vulnerable participants, young children aged 11 to 18 years old, which leads to a rigorous and lengthy ethical application and approval process by the university ethics committee, as well as the Disclosure and Barring Service (DBS) check by the UK government. The meticulous review process and the researcher's careful preparations demonstrate a commitment to ethical research practices and a dedication to ensuring the safety and respect of participants' rights. This approach enhances the credibility and validity of research findings, particularly when working with vulnerable children (Einarsdóttir 2007). In practice, as this research involves participants under 18 years old, both assent from the children and consent from their parents were required. The researcher prepared handwritten assent forms for children, taking into account that not all students had devices to sign digital forms, which was particularly challenging for less privileged students. Obtaining consent from parents proved to be a difficult task, and delays occurred in some research visits if consent forms were not collected in time. The researcher did not have direct access to parents and relied on coordinators to act as a communication bridge. As highlighted in Section 4.1, establishing excellent relationships and receiving active support from school gatekeepers proved to be crucial when conducting research with children.

5 DISCUSSION AND CONCLUSION

In summary, quantitative surveys are widely used in STEM outreach evaluation owing to their advantages of low-cost, time-saving and easy-to-use features. Yet such approaches lack a contextual understanding of STEM outreach by capturing children’s interaction with the learning environment, learning materials, peers and instructors. Therefore, this research developed a qualitative methodology design combining Multiple Case Studies and Grounded Theory with associated methods of observation, focus groups and semi-structured interviews, to highlight the potential of using a qualitative approach in STEM outreach evaluation and spark further methodological discussion within the engineering education community. This research will contribute to knowledge by adding evidence of this innovative methodology design in engineering education.

While it is acknowledged that this research design incorporating multiple research methods can be resource intensive, and may be feasible in the context of a large-scale programme with greater access to resources. The standard framework developed through this research holds the potential to benefit evaluations that lack the necessary capacity, enabling a comprehensive understanding of the impact and effectiveness of STEM outreach initiatives.

After clarifying the rationale of conducting qualitative research in STEM outreach evaluation, the reflection on the fieldwork experience is also discussed to share the best practices as follows.

Table 1. Best Practices for STEM outreach evaluation fieldwork

Access to the field
- Establish rapport with school gatekeepers through efficient communication. - Gain insight into the school's context and address concerns by providing clear and transparent information about the research. - Highlight the benefits of the research to the school community and maximize networking opportunities.
Unpredictable research environment

- Recruit slightly more student participants and expand the number of focus groups to account for potential absences. - Carefully consider the implications of any changes to the research design to ensure validity and reliability. - Have a teacher present during data collection to address behavioural issues and maintain a safe research environment.
Language barriers
- Tailor research protocols to the specific needs of different participant groups. - Use accessible language, pilot test research protocols, and ensure comprehension for accurate responses. - Adapt language and communication strategies to participants' needs, promote effective communication, and improve participant engagement.
Ethical challenges
- Following the rigorous ethical application process from institutional ethics committees, and seeking guidance from local authorities about Disclosure and Barring Service check will help ensure compliance and responsible conduct in research involving children. - Obtain assent from children and consent from parents, considering the limitations of less privileged students. - Establish strong relationships with school gatekeepers and rely on their support for communication with parents.

In conclusion, it is anticipated that other researchers in the Engineering Education community can benefit from the insights and experiences discussed in this paper. The distinctiveness of the methodological approach means that the depth and breadth of data emerging out of the study will make a notable difference in academic understanding of Engineering Outreach. At a time when theoretical saturation seems to have been achieved, one final round of data collection is due before the analysis begins in earnest. There are exciting times ahead!

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Delivery of mental health training across a College of Engineering

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ABSTRACT

Mental health is of significant concern across College and University campuses. Within engineering, students have identified that they would be more likely to seek

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mental healthcare if referred by a student or faculty member. Therefore, this research to practice study aimed to encourage students to become advocates and referral agents for students in mental health distress. To accomplish this, engineering-specific mental health and wellness training was developed through the integration of quotes and data from engineering students, personalizing the training to the engineering experience. To reach nearly all engineering students (over 2,500 students), the 15-minute training was delivered in over 60 courses. The courses were selected such that nearly all students in all years of study received the training, and preference was given to courses taught by faculty who would: 1) Support integration of the training into their course, 2) Encourage a positive narrative around prioritizing mental health, and 3) Represent the demographics of students and faculty within each program. Three graduate students from Counseling Psychology were hired to schedule and deliver the training. Pre- and post-test data found that students' perceived knowledge about mental health resources and signs of a mental health concern increased. There was no change in intention to seek help. Moving forward, the training will be offered to all students on a yearly basis to 1) provide students with an up-to-date list of mental health resources on campus and 2) remind students of the importance of advocating for themselves and their peers.

1 INTRODUCTION

1.1 Student mental health

The mental health of university students has been of increasing concern worldwide. Transition to university can lead to significant changes in lifestyle (routine, diet, independence, etc.) that can induce stress. Further, many mental health disorders do not manifest until emerging adulthood (i.e., 18-25 years old) which overlaps with the traditional age of university students (Kessler et al. 2007). The Covid-19 pandemic led to further concerns around student mental health worldwide (Salimi et al. 2023). Mental health distress has been linked to decreased academic performance and retention, highlighting the importance of prioritization of mental health on university campuses.

1.2 Mental health in engineering

Within engineering, students are exposed to a high-stress academic environment that can impact mental health. Of serious concern, research within engineering shows that mental health distress differentially impacts students who are traditionally underserved in engineering, such as female and first-generation (Jensen and Cross 2021), and female and gender-expansive students (Hargis 2021). Further, engineering students experiencing mental health distress are less likely to seek help when compared to their peers outside engineering (Lipson et al. 2016). Studies within engineering have aimed to understand the impact of mental health interventions on student outcomes, as recently reviewed in (Tait, Hancock, and Bisset 2022). While mindfulness training showed promise for improving mental health outcomes for engineering students, the review highlighted the lack of experimentally validated mental health interventions for engineering students. Therefore, this study aimed to integrate and assess a mental health intervention across the College of Engineering with the goal of increasing mental health literacy in engineering students.

2 METHODOLOGY

2.1 Development of mental health training

The 15-minute mental health training was developed by the research team based on the results of prior research on mental health related help seeking in undergraduate engineering students (Wright et al. 2021, Ban et al. 2022). The team had significant expertise in mental health training based on the education and experiences of one faculty member and three graduate students in Counseling Psychology, as well as one faculty member in chemical engineering. Additionally, university administrators engaged in mental health training and service delivery were consulted to ensure the training content was up-to-date and in line with university guidelines. Finally, the training was piloted with one graduate and three undergraduate engineering students to ensure the content met the needs of the engineering student body.

2.2 Delivery of the training

The 15-minute mental health training was integrated into courses across the College of Engineering. Three graduate students from Counseling Psychology were hired to deliver the in-class training. Each student received $1,000 in monetary support for approximately 30 hours of work on the project. In addition to delivering the training, they facilitated scheduling of the sessions and collection of pre- and post-test data.

To identify courses, department chairs were contacted and asked to identify courses that would: 1) reach all students across all years of study within the major, 2) limit the overlap of students across courses, and 3) be taught by faculty that would: support the integration of the training into their course, encourage a positive narrative around prioritization of mental health, and represent the demographics of students within their program. After receiving a list of courses from each department chair, faculty were contacted by the graduate students, informed about the initiative, and asked to choose a day for integration of the training within their course. Both the department chair and associate dean for administration and academic affairs were included in the email to showcase administrative support for the initiative. For faculty that chose not to integrate the training into their courses, an out of class session was offered to students, as well as an online video of the training recorded by the graduate student.

2.3 Pre- and post-test data collection

After obtaining approval from the university institutional review board, pre- and post-test data was collected from students to assess the following: 1) knowledge of resources on the university campus (a 10-question multiple choice quiz), 2) perceived knowledge of and access to mental health resources, 3) perceived knowledge about recognizing students in mental health distress, and 4) intention to seek help for a mental health concern. Before starting the survey, students were asked to provide consent for participation in the research study. If a student decided not to participate in the study, they were taken to the end of the survey instrument. Perceived knowledge and intention to seek help were measured on a 6-point Likert scale. Further, students were asked to indicate how much they agreed with the following statement: “During my time as an engineering student, I will need to prioritize my academic success over my mental health.” Qualitative data soliciting feedback on the training was also collected through open-ended responses in the post-test. The pre-tests were sent to students prior to the mental health training by the faculty member teaching their course. The post-tests were first advertised at the end of the mental health training and a follow-up email was sent out by the faculty member teaching their course.

3 RESULTS

3.1 Mental health training

Mental health training topics were chosen based on prior research that shows that engineering students: 1) feel that they don’t have time to prioritize their mental health, 2) are less likely to seek help for their mental health, 3) feel that they would be more likely to seek help if they received help from a friend or peer and 4) normalize the stress of the engineering training environment (Lipson et al. 2016; Jensen et al. 2023; Jensen and Cross 2021; Wright 2021; Ban et al. 2022). Five key topic areas were covered (Table 1).

Table 1. Summary of the content of the engineering student mental health training

Topic	Key content covered
Prioritizing mental health	• Engineering students feel they do not have time to prioritize mental health • Long-term stress linked to decreased academic performance and increased mental health disorders • Coping strategies can improve current and future well-being • Engineering students are less likely to seek help for their mental health
Advocating for yourself and your classmates	• Support from a friend can significantly increase help-seeking • Knowing how to recognize signs of distress can allow you to advocate for yourself and others
Recognizing normal stress vs. distress	• The difference between normal stress and mental health distress • Signs and symptoms of mental health distress and substance use • Talking to someone who is displaying signs of distress
Mental health resources	• Overview of campus resources related to mental health and wellness • Additional resources to support overall well-being (e.g., basic needs, financial support, etc.)

In addition to tailoring the content toward the needs of engineering students, quotations were incorporated from qualitative interviews with engineering students. For example, a quote was shared highlighting how engineering students feel that they cannot prioritize their mental health, “You have to prioritize the education and the work that goes towards it instead of…yourself…I think a lot of people think that it's just four years…They need to get through the school and then it'll be fine” (Wright et al. 2021). Additionally, a quote was shared when talking about the importance of advocating for the mental health of those around you, “I would be relying on the people around me to say something because in the back of my mind, I would be trying to convince myself that it's not a big deal” (Wright et al. 2021). These quotations helped to center the voices of students in the training.

3.2 Delivery of training

Ninety-five percent (57) of the 60 faculty members who were contacted agreed to the incorporation of the 15-minute mental health training into their course. In addition, 11 faculty agreed to an additional 15-minute discussion session that would be facilitated with the students in their class. Over a two-week period, the three graduate students visited the classrooms to deliver the mental health training. A total of 2,592 students were enrolled in the courses in which the training was delivered, which represents over 90% of the students enrolled in the College of Engineering.

3.3 Pre- and post-test results

Pre- and post-test data were collected to look at the impact of the mental health training on student's knowledge and beliefs about mental health and help-seeking (Figure 1).

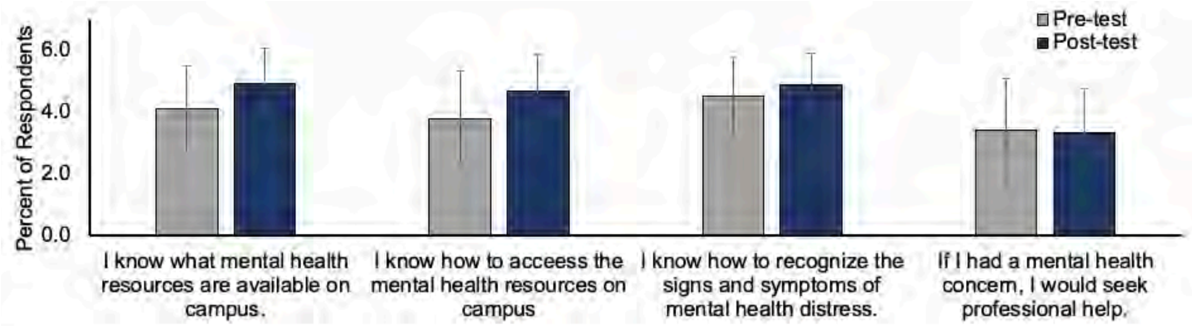

Fig. 1. Results from pre-test (n = 160) and post-test (n = 285) on mental health training. * indicates statistically significant different ($p < 0.05$) between pre- and post-test mean scores.

The training resulted in a statistically significant increase in student's perceived knowledge about and access to mental health resources on campus. This is consistent with the results of the pre- and post-test scores for knowledge of campus resources which increased from an average score of 32% to 55% after the training. Students also felt that their knowledge about recognizing the signs and symptoms of mental health distress increased. There were no changes to students' intention to seek professional help.

Of interest, students were asked to indicate how much they agreed with the statement, "During my time as an engineering student, I will need to prioritize my academic success over my mental health" (Figure 2).

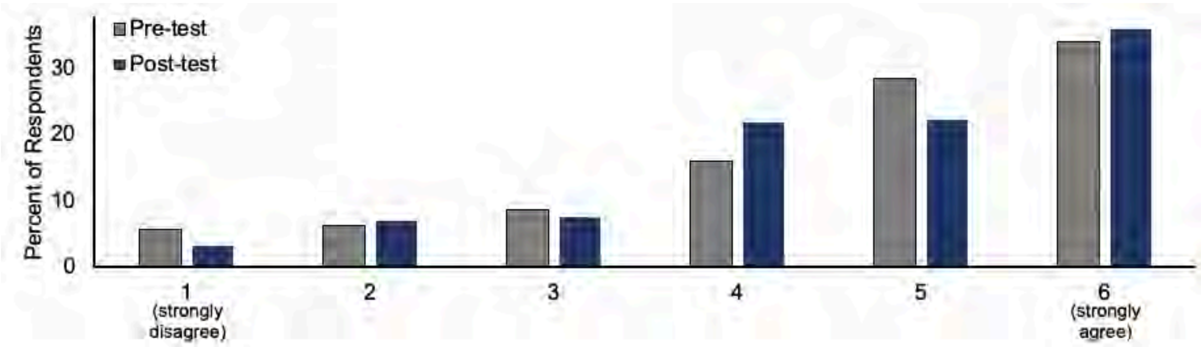

Fig. 2. Student agreement with the statement, "During my time as an engineering student, I will need to prioritize my academic success over my mental health."

While there was no significant difference in the pre- and post-test responses, over 60% of students somewhat or strongly agreed that they would have to prioritize their academics over their mental health. This provides important insight into the mindset of engineering students as they navigate their engineering training.

In addition to the quantitative data from the pre- and post-tests, qualitative data was collected to solicit feedback on the quality of the training. Some of the key themes related to the benefits of the training are summarized in Table 2.

Table 2. Summary of themes related to benefits of the mental health training

Theme	Quotation
Realizing I am not alone	"Learning that half of all engineering students also have gone to counseling or therapy. Made me feel like it's not just me."
Interesting to see data	"I think it was interesting to see the statistics about the number of engineering students who had actually used mental health compared to non-engineers."
Nice to acknowledge mental health	"It is really nice to recognize and talk about these things, as well as seeing all the resources."

The qualitative data highlights the importance of the training as well as engaging in conversations about mental health in engineering classrooms.

4 SUMMARY AND ACKNOWLEDGMENTS

With the prevalence of mental health disorders increasing in university students, it is important to develop strategies to support student mental health. This study aimed to deliver mental health training across a College of Engineering. The 15-minute training was incorporated into 60 courses with nearly 2,600 enrolled students. Pre- and post-tests of the training indicate that student knowledge about mental health resources on campus was increased, but their intention to seek help was unchanged. Qualitative data indicated that the training helped some students not to feel alone in their mental health struggles, which is an important outcome of the training.

While ideal training would lead to differences in both student knowledge and intention, it was not anticipated that a limited training of just 15 minutes would lead to significant changes in beliefs. Literature shows that mental health literacy is significantly correlated with help-seeking behavior (Gorczynski et al. 2017), indicating that changes in knowledge could be a strong step toward future change in behavior. Future interventions aimed at the normalization of mental health and help-seeking could result in further changes in student's attitudes and intentions to seek help for their mental health.

It is also important to acknowledge that the onus for change does not sit solely in the hands of the students. Currently, students face structural barriers that prevent them from prioritization of their mental health throughout their education. For instance, the high academic workload in engineering and normalization of stress puts pressure on students to solely focus on academics rather than finding balance in their lives. Faculty and administration within engineering need to help deconstruct these norms and give students permission to prioritize their well-being. Future interventions should be aimed at faculty and administration to create a culture that is supportive of mental health in engineering. This would include guidance on how to support a culture of well-being, as well as policy changes that provide students with the agency to prioritize their mental health as they pursue their engineering training.

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(RE)DEFINING ENGINEERS' RESILIENCE: PART II REFLEXIVE ACCOUNTS OF DOING REFLEXIVE THEMATIC ANALYSIS

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ABSTRACT

This work accompanies another paper which describes interpretivist qualitative research that made use of data from semi-structured interviews pertaining to how engineering educators conceptualize resilience and support students in its development. In that work, we utilized reflexive thematic analysis (RTA) for several reasons. Firstly, it is considered a useful method for under-researched areas. Secondly, its flexibility allows for inductive and deductive theme generation. Finally, it is considered a reasonably accessible method which we believe is important when considering 1.) the varied audience of engineering education research (EER) and 2.) the relative lack of consensus as to acceptable theoretical frameworks or methodologies for use within the space. In taking this approach, and in acknowledging its flexibility, I consider what that means for the process. RTA is not accompanied by a distinct theoretical framework, meaning researchers must clearly communicate methodological decision-making. In situating myself as an interpreter of meaning I recognize the need to share the role I play in knowledge production. Finally, being relatively new to qualitative research, I wanted to document my struggles and capture

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ways my practice has developed. I, therefore, document my reflexive process in relation to the six-stage process proposed by Braun and Clarke.

1 INTRODUCTION

In many cases, the researchers and audience involved in engineering education research (EER) will be trained in quantitative approaches and although there exists a preference for positivist studies (Beddoes 2014; Pawley, Schimpf, and Nelson 2016; Riley 2017), a wide variety of epistemologies, theories, and methods are present within the literature (Beddoes 2014). Historically, the orientation toward positivism is shaped by efforts to establish EER as a discipline, and quality criteria have been aligned with concepts of rigour (Streveler and Smith 2006). This is particularly true of the American context where these aims are heavily influenced by the National Science Foundation (Beddoes 2014, 293-312) who fund most EER. Riley (2017) claims that EER researchers fail to draw equally on all forms of 'rigour' but exhibit preference for those conforming with 'engineering rigour'. Borrego, Douglas, and Amelink (2009) describe how reviewers at an EER conference showed a lack of acceptance and understanding of qualitative work.

The reliance on quantitative methods has come under criticism, particularly by those who encourage critical research approaches. For example, Slaton and Pawley (2018) claim that the preference for 'large-n' studies means that "some stories are never studied" (p. 137) and highlight the role of "small-n" studies in allowing for a critique of discriminatory engineering education practices. However, a shift towards the use of qualitative methods necessitates "a coherent language and conceptual framework to critically engage with questions of qualitative research" (Walther et al. 2017, p. 398), Koro-Ljungberg and Douglas (2008) found that for the few qualitative studies published in the Journal of Engineering Education (JEE), there existed inconsistencies in epistemologies across research design, something they claimed limits their contribution. In a response to the number of qualitative research studies rejected from the Journal of Engineering Education (JEE), Baillie and Douglas (2014) encouraged authors to consider "the complete research design – to include the epistemological stance taken, the methodology and methods used, the role of theory, and the relationships among all of these" (p. 6). Kellam and Cirell (2018) suggest that it is "easy to gloss over methods sections without providing ample detail for new readers to understand participant selection, data collection, data analysis, and subsequent conclusions" (p.356) and that those details are needed to enable the reader to understand how researchers arrive at conclusions, the specific context of research, and subjectivities as researchers. This, they say, is critical to allow the reader to gauge the trustworthiness or validity of studies. It is, in part, in response to these concerns that I write this paper in which I document my reflexive process in relation to the six-stage analytical process proposed by Braun and Clarke (2006) and consider the roles of personal, functional, disciplinary, introspection and intersubjective reflexivity as well as mutual collaboration.

1.1 Thematic Analysis (TA)*)*

In broad terms TA is referred to as “a method for developing, analysing and interpreting patterns across a qualitative dataset, which involves systematic processes of data coding to develop themes” (Braun and Clarke 2022, p.4). TA may appear attractive to researchers within EER as it “offers an accessible and robust method for those new to qualitative analysis” (Braun and Clarke 2022, p.4). The diversity in approaches to TA and its flexibility “with regard to theory, research question, data collection method, dataset size and generation strategy, and analytic orientation…and purpose” (p. 261) allows for its widespread application within research and, indeed, is the reason for its popularity. However, this flexibility means it is difficult to offer precise ‘rules’ resulting in ‘good’ TA (2021). Since the initial publication of their approach to thematic analysis, Braun and Clarke (2006) have identified issues in the “coherence and integrity of published research” (2021, p.328) claiming to have adopted their approach. Part of the reason for such ‘problematic practices’ (Braun and Clarke 2021) and ‘conceptual mismatches’ (Braun and Clarke 2019, p.589) is the lack of published work which describes doing TA (Trainor and Bundon 2021) which leads to limited understanding about different types, and the active choices and decisions made by researchers. This makes it difficult for researchers to learn from one another, and thus for the development of quality TA. In making use of the term reflexive TA (RTA), Braun and Clarke (2019) situate researchers as interpreters of meaning, framing subjectivity as an asset.

2 CONDUCTING RTA

2.1 The Researcher

Below I have outlined aspects of my positionality in relation to the six aspects of research outlined by Secules et al. (2021).

I am currently an engineering lecturer and therefore consider myself as an ‘insider’. I was trained and socialised within a positivistic paradigm, and it is only in the last few years that I have become interested in engineering education. I am sensitive to arguments around the lack of rigour associated with qualitative research, which are prolific within my working environment, and I have previously conducted research which focused on how EER is perceived, recognized and rewarded within the UK (Wint and Nyamapfene 2022). I have been encouraged to help students develop their resilience but have received little response when questioning what colleagues (educators and those involved in employability) mean by this, why it is perceived necessary, and how it may be done. In part, this research was born out of a frustration I felt for the careless use of terms related to complex psychological constructs, something which I often associate with a lack of respect for other disciplines. I, myself, have been told that I should exhibit more resilience on numerous occasions, often in reaction to speaking about the upset I feel after experiencing, what I consider, injustice. I also feel conflicted in knowing that students can feel discontent when faced by challenging situations such as those that may help develop resilience. This is of concern for me as a junior academic, given the increasing focus on, and influence of, student satisfaction surveys. I am aware that part of my desire to write this paper is a result of a lack of deep engagement with the RTA process when claiming to adopt thematic analysis as defined by Braun and Clarke (2006) during previous work.

2.2 The Research

The work accompanies another paper which describes an interpretivist qualitative research project (Denzin and Lincoln 2003; Lincoln and Guba 2005; Smith 1992) that made use of semi-structured interviews to collect data pertaining to how 13 engineering educators conceptualize resilience and their approach to helping students develop resilience. We (this research was conducted with another researcher, referred to as ‘Researcher B’ within this work. ‘We’ thus refers to decisions made together) decided to utilize RTA to analyze the interview data for several reasons, primarily because it was well suited to answer the research questions and aligned with paradigmatic underpinnings of the research. Secondly, it is generally considered as a useful method when studying under-researched areas (Braun and Clarke 2006) and its flexibility allows for inductive and deductive theme generation which captures semantic and latent meaning. In taking this approach, and in acknowledging its flexibility, we must also consider what that means for our process. For example, RTA is not accompanied by a distinct theoretical framework, meaning that researchers must ensure clear communication of methodological decision making. Similarly, in situating ourselves as interpreters of meaning and framing subjectivity as an asset (Braun and Clarke 2019), we recognize the need to communicate our role in knowledge production.

2.3 Data Collection

I acknowledge that my positionality has shaped not only the research topic and questions, but also the process, including data collection and interpretation. In many ways my identity helped in understanding participants and their perspectives and in building rapport and trust. However, I also recognize the tendency for my views, thoughts, and ideas to become intermixed with those of participants. I thus made regular journal entries throughout data collection. Entries were typically made directly following an interview and included details about my emotions, thoughts, and any questions I had. In some cases, interviews were long and emotionally draining, and my initial reflections were limited and thus supplemented in subsequent days. In some cases, journal entries informed changes to my interview technique, for example rephrasing questions. I occasionally engaged with Researcher B in post interview debriefs and sent transcripts intermittently. Below are exemplar journal entries.

I felt really happy and excited when [participant] said something that I believe to be true. It feels like a magical moment when you get those golden quotes that express the story you want to tell. Maybe it is also to do with validation. But I feel guilty for feeling this way. I feel like I should not have feelings about the findings of research. I will send [Researcher B] the transcript and ask for their opinion to see whether they agree with my interpretation.

I feel like maybe I became too relaxed when interviewing [participant]. It seemed more conversational, as if we were discussing and debating rather than me asking the questions. I *hope I wasn't too leading in asking questions or making too many suggestions about what an answer might be. I will have to discuss this transcript carefully with [Researcher B].*

An example of an extract mentioned in the second journal entry is shown below. The participant in this case is a white, male research professor who I have known for over ten years. The individual has played a large role in my professional development and acted as a mentor. We frequently engage in friendly debate. I was surprised when the individual contacted me to take part in the research but upon interviewing them, it was clear that they had a strong interest in the promoting resilience.

Researcher: Okay umm, so a sort of aside but linked to this, like what's your view on how we develop resilience in students who are high achievers? So, what do you think of students who are used to achieving very high marks, just sort of sailing through their degree and then are exposed to the workplace or research?

Participant: Well, I think there's a misconception in your question that the students who achieve high marks are sailing through. They might appear to be but behind the scenes they're often working as hard, harder than anybody else. Those students are already resilient is my answer. I don't think you can be a high achiever without it.

Researcher: Yeah, that's interesting, I mean, I've been thinking about this…like I would consider myself a high achiever and I know that I really struggled like with research and the workplace… like it's a mixture of resilience and other things, but I was just so used to knowing what I had to do to succeed and just getting a high mark and knowing I could do that, that I just wasn't able to… it took me ages to…

Participant: Okay, let me have another crack at answering because I'm not even sure that I believe my initial answer. I think that there's a combination of two aspects drive and resilience. And there's a lovely book by Malcolm Gladwell which compares what it's like to be a big fish in a small pond or small fish in a big pond and how you adapt and how you develop in that scenario. And I think those students… high achievers… so alright, I was quite premature in giving my answer as bold as it was. I think perhaps those students have good drive. But I know students who are the best in the class and then go off to Oxford and they are no longer the best in their class and they leave and that's not particularly indicative of resilience necessarily. But then, if you're not enjoying it, why should you stick around? That's more intelligence than resilience. But certainly, you know, there are scenarios where that does happen, and those are high achievers. So yeah, okay I'm not even sure if I agree that you should link high achievement with resilience, I think you can probably link high achievement, with high drive. And then the unlikelihood to have to demonstrate resilience.

In the extract, the participant, at first, claims high achievers are resilient. Once I share my experience of struggling outside of an education setting, they admit to being *"quite premature in giving my (their) answer as bold as it was".* It appears my views have swayed theirs. In reading the transcripts I was disappointed in myself for being, what I considered, too leading, and focusing on my views as opposed to those of the interviewee. However, I also believe that the extract illustrates the role that researchers play in knowledge production. I also wonder if the extract demonstrates that findings are not necessarily always about the views of the participant, but that a finding could also be that the concepts discussed are complex and thus responses are nuanced. In this case the extract suggests contradictions in how educators understand resilience and the factors which influence it which is, in itself, an important conclusion.

2.4 Data Analysis

Throughout this section, I document my reflexive process in relation to the six-stage analytical process proposed by Braun and Clarke (2006).

Familiarization with the dataset: This “involves both closeness and familiarity (immersion) and distance (critical reflection)” (Braun and Clarke, 2022, p. 43). After completing interviews, I transcribed the audio recordings verbatim and read each transcript. I made journal entries of thoughts, ideas and emotions encountered. I found it helpful to distinguish between thoughts regarding data interpretation and those about my role in constructing knowledge. Upon re-reading each transcript I began to make notes (as comments within Microsoft Word) about ways in which I was making sense of the data. For each transcript I produced a document summarising overarching thoughts. After re-reading the transcripts I revisited each of the comments and questioned several things including i.) reasons the participants may be making sense of resilience and its development in the way they were ii.) whether they made any assumptions iii.) whether their sense making was consistent with what was considered ‘normal’ or what I had expected, iv.) whether there were reasons I may be interpreting the data the way I was and v.) whether the data could be interpreted in other ways. In some cases, I wrote possible answers to these questions on the transcripts. I then produced a summary document which included potential patterns across the dataset.

Coding: Coding involves working through the entire dataset and “identifying segments of data that appear potentially interesting, relevant or meaningful for your research question” (Braun and Clarke, 2022, p.35). The systematic nature of coding was a bit daunting to me; perhaps I was afraid of missing a code. I started by adding comments in Microsoft Word. Later, I printed out the transcripts (with comments) for the second and third round of coding. I found that a change in environment and approach helped me to revisit the transcript with ‘fresh eyes’. Prior to coding each transcript, I read the corresponding reflexive journal entries. I then began tagging any data that I found interesting or relevant with a code label. As I read through the transcripts, I reminded myself as to whether an existing label already existed. During the first round (particularly the first few transcripts) I typically focused on semantic codes. Code generation initially followed an inductive approach (whilst recognising that pure induction is impossible). As I worked through the transcripts, I began to notice connections with the literature and started coding around theoretical ideas and concepts. I was aware that my positionality influenced what interested me, and that I have my own understanding of resilience within engineering education. I made a conscious effort to separate my personal response to data, from that which was relevant and useful to the overall analysis. Whilst considering my emotive response as an asset, I was mindful that my response would not be the only possible response to the data. A collaborative coding process was used to enhance understanding and interpretation, and to examine the limits of my reflexivity. The aim of this was to question and interrogate my beliefs regarding what I considered important rather than to reach a consensus about data coding. This felt particularly important in the case of data which I had written feeling excited about (‘golden quotes’).

As I continued coding the interviews, I moved back to make notes on other interviews, particularly when there were similarities and differences. I noticed the first few transcripts were heavily coded, and that not all codes were relevant to the research questions. I continued by making a conscious effort to revisit my research questions. I also felt afraid to code something I knew was unique to one participant. I tried to remember that an individual data item can contribute towards development of a theme.

After coding two or three transcripts I began to feel that I had a good grasp of the data and similar codes were being noted in multiple transcripts. However, I realised that some of my code labels lacked nuance and depth and were being used to capture multiple meanings instead of a singular idea. I was guided by Braun and Clarke's (2013) suggestion that 'good' codes "capture the essence of what it is about that bit of data that interests you and informative enough to capture what was in the data, and your analytic take on it" (p. 210). My codes therefore evolved throughout the process. For example, the original code label 'factor influencing resilience' was parsed out to include information about each factor. I began to feel more confident in my ability to code once I started identifying patterns. There was also a feeling of satisfaction associated with condensing data into a neat set of codes.

I read the transcripts three times, each time in a different order. During the second and third round I sometimes added codes (normally similar to those noted for the later transcripts of the first coding round), and refined code labels. There were between 25 and 45 codes per transcript. The variability in the number made me feel slightly anxious. I tried to remind myself that interviews varied in length, but also that I had been trying hard to ensure coded data was relevant to the research questions and that "some segments of data will not be tagged with any codes, because there isn't anything of relevance to the research question." (Braun and Clarke 2022, p. 53).

All codes were noted within an Excel file alongside a reference to the relevant quote. However, this approach led me to feel as though I was losing context and I later included the relevant quotes within the same document. I then cross checked the codes. In the case that there were similar codes across interviews, I combined the codes ensuring that the nuanced differences were not lost. Finally, I compiled a list of my final codes and the data items associated with each. I ensured that I was able to read the final code labels and understand the nuance of what was meant without looking at the accompanying data. In some cases, this meant adjusting labels. I also checked that, together, my codes captured and reflected the diversity of meaning that I had commented upon within journal entries There were a total of 203 codes.

Generating Initial Themes: This phase involves "identifying shared patterned meaning across the dataset" and compiling "clusters of codes that seem to share a core idea or concept" (Braun and Clarke, 2022, p. 35). Generating themes was the most daunting part of the process to me and I was worried about generating too many, thin themes. When I started this process, I began by trying to copy and paste codes into clusters within the Word document created at the end of the coding process. However, I found this challenging and therefore printed codes out on strips of paper which could be physically moved into clusters.

Upon my first attempt I found I was moving codes into clusters aligned with some of my interview questions, for example factors influencing resilience. Clusters thus appeared to “capture a range of responses around a particular issue” (Braun and Clarke, 2022, p.77) and more similar to topic summaries than themes which have a central organising concept (Braun, Clarke, & Rance, 2014). Braun and Clarke (2022, p.90) warn that this constrains “your ability to notice patterned meaning across the dataset” and prevents “you from exploring pattens or clusters that are not immediately obvious, but that might offer the most useful and important analytic insight”. I thus started again, reminding myself of the need to consider whether codes could be grouped in a way such that they all contribute to the same core idea. As I worked through the codes, I explored three clusters I felt relevant to the research questions.

- *‘Finding the middle ground’* concentrated on extremes in the way resilience was conceptualised (*“People kept telling me that that wasn’t what resilience was.”),* and how far educators should push students to develop resilience (*‘How far is too far?’*)
- *‘Boundaries and limits’* focused on boundaries between the role of the individual and the system in resilience (‘*Resilience as highly individual but impacted by the system’*)., and the boundaried nature of educators’ roles (‘*Limits of the educator*’).
- *‘Being pulled in different directions’* is about tensions involved in developing resilience.

This is ‘work in progress’ and effort to develop, review and refine the initial preliminary themes is ongoing. I collected all the unallocated codes into a new Word document for use during theme development which would involve consideration for whether each theme 1.) captured something meaningful, 2.) captured a coherent, central idea and 3.) had clear boundaries (Braun and Clarke, 2022).

3 SUMMARY

The RTA process was both challenging and time consuming. It is recognised that had a different approach been taken (e.g., coding reliability, codebook), themes would still have been generated, but the analysis may have been less interpretive and unrepresentative of the entire data set. Instead, they may have summarised everything said about a certain concept that participants were asked about and be more descriptive in nature. Although the research questions have been partially answered and a preliminary report of findings has been produced, it is recognised that had the analysis been done at a different time and in a different context that it may be different. Indeed, the data and themes (including theme names, subthemes and which codes are included and excluded) may be questioned again when preparing a journal article. This account thus provides an incomplete story and the impossibility of expressing the complexity of the process and the movement between different stages is acknowledged. It is recognized there is no one way to conduct RTA, and that the process reported here is neither correct nor best. However, it is hoped that in sharing this experience, and being transparent about decisions and feelings during RTA, further conversations regarding conceptions of high-quality qualitative EER research are encouraged.

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Workshop Papers

SEFI ANNUAL CONFERENCE
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EMPATHY IN ENGINEERING AND ETHICS EDUCATION: RESOURCES TO SUPPORT THE ENGINEERING EDUCATION GLOBAL COMMUNITY

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***Conference Key Areas**: Engineering Skills and Competences, Lifelong Learning for a more sustainable world*
***Keywords**: empathy, engineering education, ethics*

MOTIVATION

There is no question of the importance in the education of engineering students developing ethical decision-making abilities of future leaders and innovators. Literature suggests that when learners see how ethics and empathy together play role in guiding their actions, students tolerate ambiguity and are less influenced by their peers, for example, looking at problems from different perspectives (Krznaric 2014; Feshbach and Feshbach 2011). Recently, empathy gained growing attention

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in engineering education, being related to prosocial behavior, and psychological safety in teamwork and the classroom. Empathy, simply said, is a human quality to “put oneself in another’s shoes,” feeling what they are feeling with the understanding that their emotions may not be one’s own. While engineering educators have established instructional methods to teach engineering ethics, how to develop and enhance empathy competency is still challenging.

This workshop introduced practices in education that support the development and enhancement of empathy in engineering students.

During the workshop we discussed the relevance of empathy for engineering education; criteria for empathy projects/assignments and an empathic teaching framework were presented. Together we ran through empathic pedagogies of inclusion and engagement while exploring teaching empathetically within content-specific environments. Participants left the workshop with steps to design assignments that can activate student empathy in design-thinking and demonstrate inclusive teaching practices, including learning empathic techniques, resources, and tools that could benefit the Engineering Education global community in building students’ empathic capacity.

BACKGROUND AND RATIONALE

Empathy is the human quality of understanding or feeling what another person is experiencing from the other person’s perspective. To exercise empathy means to understand the motives, needs and points of view of others, thus, empathy is considered an important factor of moral behavior, and an essential component in forming moral communities (Ehrlich and Ornstein 2012). According to the European Educational Policy report (European Educational Policy Network 2020), both empathy and ethics are based on an understanding of the following four attributes: values (human dignity and human rights), attitudes (sense of responsibility and respect), skills (listening, observing, and cooperation), and knowledge and critical understanding of self. Having these four attributes, the report suggests, a person can perceive multiple perspectives and engage with people from diverse backgrounds. These attributes are perceived as essential active citizenship skills for teaching and learning in the digital age (Council of Europe 2019). Further, research suggests that empathy education can produce citizens who care about community issues such as poverty, war, and climate change (Krznaric 2014). In fact, empathy training could help the world come together to address significant issues such as “climate change, poverty, escalating violence, international conflicts, [or] illness” (Ehrlich and Ornstein 2012, p.15).

Caring for a fairer, more resilient future, it is our obligation to prepare students with the skills and human qualities that will foster good global citizenship. As educators, one of our jobs is to help students learn empathy as they also learn from current events and history about wider definitions of diversity, equity, and inclusion. In the engineering classroom, when we create and foster learning experiences, such as the practice of empathy, we support a broad set of important learning objectives that are not easily addressed in a traditional engineering curriculum (Bairaktarova 2022).

WORKSHOP DESIGN

In the workshop, participants were introduced to the "The Human Face" activity[2]. This activity promotes perspective-taking, creative writing and artistic expression. In this activity, participants work in groups on specific situations (scenarios related to current global issues, e.g., the 2023 Earthquake in Turkey).

Participants were instructed to start by analysing the scenario individually:

- read the scenario on the sheet and put a human face on the issue;
- imagine a person living in those circumstances and describe that person's experience;
- imagine what the person looks like, give them a name, and imagine as much detail as you can concerning the conditions in which they are living.

Following this initial engagement with the scenario, participants discussed the following questions in their small groups:

- Did you feel empathy for the person you imagined?
- is putting an individual human face on global issues important to activating empathy for large groups
- what impact can individual stories have in promoting an active response or social action?

RESULTS OF THE WORKSHOP

This workshop introduced creative ways of teaching empathy through empathic techniques and design thinking philosophy in an engineering content-specific learning environment. The relevance of empathy for engineering education was discussed; Participants were encouraged to think about learning activities that reward risk-taking and vulnerability; develop and enhance students' empathic ability; and ensure student success in designing human-centered projects. These types of interactive activities and dynamic discussions draw on the latest theories on empathy and design thinking (Kouprie and Visser 2009) related to education. They help inform and shape techniques and strategies needed to successfully teach students to become adept with diverse peoples and ideas, to collaborate, and to contribute more and better ideas through listening, observation, and cooperation.

Participants left the workshop with resources on how to design assignments that will activate student empathy in decision-making and design-thinking. Participants were invited to join the "Caring for the Future: Emapthy in Engineering Education" project and get access to the project resources, including participating in the monthly global webinars.

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[2] https://worldslargestlesson.globalgoals.org/resource/the-human-face-of-food-investigations-in-social-science/

Empowering engineering learners by including empathy in the engineering curriculum can help to produce altruistic, more compassionate citizens who can direct their energies toward problem-solving that improves society.

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TECHNIQUES IN TEACHING ENGINEERING ETHICS AND PROFESSIONAL RESPONSIBILITY

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Conference Key Areas: *Embedding Sustainability and Ethics in the Curriculum*
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1 BACKGROUND AND RATIONALE

Engineering education has evolved to include engineering ethics and professional responsibility as integral to the curriculum. Accreditation requirements emphasize this part by including the broader impact of engineering, especially ethics, as a major part of student educational outcomes. As a result, engineering educators and instructional designers have developed innovative techniques and methods to deliver engineering ethics during undergraduate engineering education and beyond. This is despite the inherent challenges associated with any engineering curriculum, particularly capacity and integration. Regarding curriculum capacity, engineering curricula are always jampacked with content, making adding more content another optimization problem during instructional design. Meanwhile, components' integration is always needed to help combat and reduce the problem of knowledge and skills compartmentalization taking place cognitively and practically among students due to many inherent factors. Furthermore, the integration problem is augmented by the challenge of teaching non-technical content as part of a technical course or curriculum. Therefore, teaching engineering ethics and professional responsibility takes extra effort to be included and integrated into engineering.

Many techniques and methods exist to teach engineering ethics. Also, many experts have been teaching ethics for a while. However, many new instructors and engineering trainers have joined the workforce. The goal of this workshop is to refresh the basic concepts and foundational ideas for teaching engineering ethics and professional responsibility, as well as an overview of available techniques and levels of engagement, which could be employed by different instructors based on their own curricular context. The workshop will expose participants to foundational topics and relevant techniques in teaching engineering ethics and professionalism. Participants will be engaged in active learning guiding them to plan their offering of engineering ethics to engineering students, at their respective institutions and curricular context, with consideration of the unique cultural and societal aspects of different geographical locations, and with a view on how to integrate engineering ethics across the curriculum as an essential part of engineering knowledge.

2 WORKSHOP DESIGN

The workshop was designed to include the following topics:

- Fundamentals of engineering ethics education
- Techniques and methods to teach engineering ethics
- Design and planning different modules for classroom delivery
- Assessment evaluation integration.

To achieve the goals and cover these topics, the structure of the workshop had three phases:

1. The frame: goal and limitations of teaching engineering ethics
2. The content: selection of material and delivery technique
3. The product: building an integrated teaching module (content, delivery and assessment).

The workshop started by asking the participants four questions using SpeakUp poll service, in order to capture the challenges related to teaching engineering ethics.

Participants were allowed to vote for multiple answers for each of the four questions, including the reasons for teaching ethics, challenges and limitations in teaching ethics, priority issues in ethics education and techniques in the delivery of ethics education content.

A team activity was implemented in the second part of the workshop through which the participants were asked to brainstorm and design a draft module for teaching ethics in engineering education courses.

3 RESULTS OF THE WORKSHOP

The first question asked the participants for the reasons for teaching ethics. The participants could vote for multiple answers from seven predefined choices. The three most often voted reasons for teaching ethics were the following (n=15):

- Educate engineers about professional responsibility (93%)
- Build moral reasoning among engineers (80%)
- Sensitize engineers to potential ethical issues (73%).

The second question asked about the challenges and limitations of teaching engineering ethics. From the nine options, the participants' (n=17) top-voted choice was *Curriculum is at capacity (full) preventing any additions* (73%). Other answers included:

- Non-technical topic between technical subjects (41%)
- Lack of institutional support (29%)
- Students don't like ethics (24%)
- I don't have time to plan implementation (24%).

In the third question, the participants (n=19) were asked to choose what is a priority in teaching engineering ethics from eight options. The answers were divided more equally with three top choices being: *Understanding evolving issues* (58%), *Why needed* (53%) and *Know how to practice proper engineering* (47%).

Finally, the fourth question asked the participant (n=19) about the techniques available to teach engineering ethics, with nine options to choose from. The most often voted choices were

- Module or more (58%)
- Spiral – more focus as the students progress through the curriculum (53%)

The third place was shared by three choices *Case study based*, *Added to a course*, and *From outside engineering (other department)* (42%).

Before the workshop's group work, some examples from existing implementations of ethics on courses were presented. In the actual workshop activity, 12 teams with 2-4 team members, created in 20 minutes a plan for a module to teach engineering ethics. Teams designed both incremental as well as innovative new implementations during the activity and shared their designs with others.

4 CONCLUSIONS AND SIGNIFICANCE FOR ENGINEERING EDUCATION

This workshop focused on providing the space for educators and course designers to share their experiences and explore potential solutions to hurdles when it comes to integrating ethics into engineering education. Engineering ethics enthusiasts are painfully aware of how compact and dense the engineering curriculum is, and as the results of the introductory questions suggest, it is obvious that most find this aspect most difficult when it comes to adding new content.

Nevertheless, the enthusiasm persists and, as participants of the workshop have also confirmed, educating the next generation of engineers about professional responsibility as well as building moral reasoning into how engineering is conceptualised, is highly important.

The workshop managed to create a space for discussing these points among engineering educators and, more importantly, there was a moment in which solutions could be discussed in a practical and tangible way.

HELP THEM GROW – THE ENG-IST TOOL – SUPPORTING STUDENTS' PERSONAL DEVELOPMENT PROCESS TO STIMULATE LIFELONG LEARNING

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Keywords: Lifelong Learning, Personal Development Process, Supporting Students,ENG-IST Tool, Supporting Lecturers

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1 MOTIVATION AND LEARNING OUTCOMES

Teaching staff often acknowledge the importance of Lifelong Learning (LLL) competencies but they do not necessarily feel adequately prepared to support students' personal development towards obtaining these important skills. TRAINeng-PDP is an Erasmus+ project which aims to prepare students for a life full of learning through a personal development process (PDP).

One outcome of the project is an Engineering Programme - Intervention Selection Tool (ENG-IST) to assist lecturers in choosing appropriate interventions for the engineering classroom which support the students' personal development process. Our motivation in this workshop is to showcase, test and enhance the ENG-IST tool so that once complete it is a highly relevant, broadly applicable and context specific resource for the engineering education community.

Specifically, participants of the workshop will be able to;

1. Recognize the variety of interventions that are available to support the PDP of students
2. Reflect on their own teaching to identify a module which would be suitable for an intervention
3. Co-create an intervention design appropriate to a specific context
4. Discuss the constraints associated with the implementation of a particular intervention

2 BACKGROUND AND RATIONALE AND RELEVANCE

The project team undertook a scoping review to identify which types of interventions have already been successfully implemented in higher education more generally (van den Broeck et al., 2022). We used these findings and the contextual aspects of how they were implemented to create the ENG-IST tool to be appropriate to the engineering classroom. The ENG-IST tool is a flowchart which identifies the most appropriate intervention for a particular context, and the educator's aims, based on different criteria and preconditions (Fig. 1). Some considerations include:

- Focus of the intervention (type of skill to be developed)
- Investment required from students,
- Class-time devoted to PDP,
- Type of feedback,
- Other developed skills,
- Preparation time for lecturers,
- Follow-up time for lecturers.

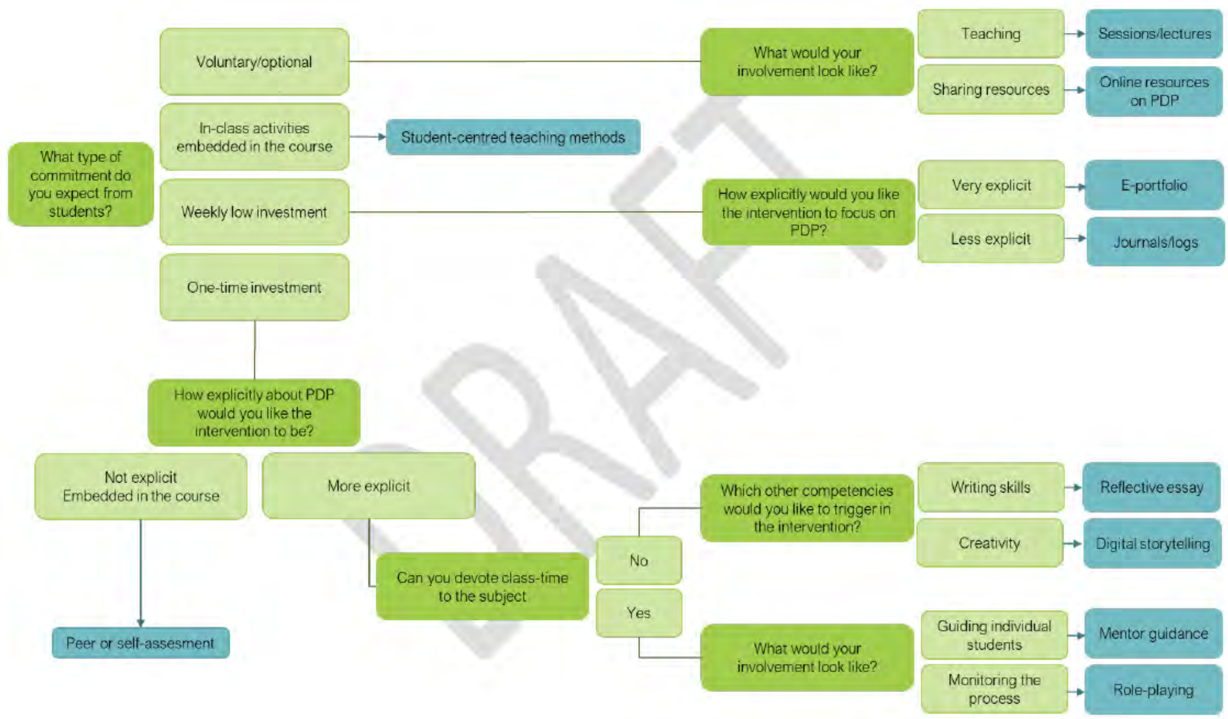

Figure 1: Draft ENG-IST Tool

Educators can use the flowchart to select an appropriate intervention for a particular context. As a further resource for educators, we have also drafted instructional "How To" guides for each type of intervention. We wish to improve the quality of the ENG-IST tool and the intervention guides in this workshop by testing, co-creating and enhancing the tool and instructional guides for specific interventions.

3 WORKSHOP DESIGN

0-10 mins - Short introduction to the workshop, explanation of interventions identified in the literature as part of the scoping review (van den Broeck et al., 2022). (LO 1). Full presentation is included in Appendix A.

10-15 mins- Individually, participants reflect on their own teaching and choose a module that would be suitable to introduce an intervention. Using a Context Template, they record the constraints and contextual considerations associated with this module. (LO2 and 4)

15-20mins- The ENG-IST flowchart is circulated, and participants use it to choose an appropriate intervention based on their context.

20-45 mins- Participants now move to a table specific to that intervention.

Facilitators and participants co-create an Intervention How to Guide (with some sections pre-filled) gathering best practice and views from participants including any constraints. (LO 2,3 and 4)

45- 55mins- Each Group reports back (2 mins each) (LO 4)

55-60 mins - Wrap Up. Participants leave with the ENG-IST flowchart and list of interventions.

4 WORKSHOP AFTER WORK

This final workshop paper has been supplemented with the key findings of the workshop as part of the proceedings. The feedback and notes which were taken in each group on each intervention are now included in Appendix B.

The next step of the project is to trial interventions with student groups which will use the Intervention Guides created in this workshop. We hope that the participants will also be motivated to trial interventions in their own context.

5 SIGNIFICANCE FOR ENGINEERING EDUCATION AND ATTRACTIVENESS OF THE WORKSHOP TOPIC

Engineering employees need to continuously update and up-skill their competencies, to keep pace with changing technology and shifting requirements of the labour market (European Commission, 2019; OECD, 2019) hence Lifelong Learning skills (LLL) are a key component to maintain and improve employability (Employers Statement, 2019). Thus it is essential that students are facilitated in their personal development and this ENG-IST tool and accompanying guides provide a useful resource for educators.

This workshop is attractive as it is an engaging interactive session which will allow educators to become aware of the key LLL competencies students require and the appropriate interventions needed. Furthermore, educators will have some space to reflect on a module in which they could implement an intervention and to assist in co-creating an intervention guide. We hope this workshop will both motivate and support educators in implementing an intervention which we would love to hear about at SEFI 2024.

6 TARGET AUDIENCE, PARTICIPANT KNOWLEDGE REQUIRED, TARGET NUMBERS OF PARTICIPANTS AND RESTRICTIONS ON SIZE IF APPROPRIATE.

Our target audience includes engineering educators who are interested in helping students with their personal development and who are open to undertaking an intervention. No participant knowledge is required, but it would be helpful if the participants are active educators so they can consider a specific module in which to undertake the intervention. Target number is 25, max 40.

7 ENHANCEMENT OF KNOWLEDGE AND DIALOGUE ON THE WORKSHOP TOPIC.

Participants will leave not only with a useful tool for selecting appropriate interventions but also with an awareness of the different types of interventions available. The following interventions were chosen as result of our scoping review (van den Broeck et al., 2022) which investigated appropriate interventions in many different disciplines. These include;

- E-portfolios,
- Reflective essays,
- Digital storytelling,
- Mentor guidance,
- Role-playing,

- Online resources,
- Sessions/lectures,
- Journals/logs,
- Student-centred teaching methods,
- Peer or self-assessment.

The workshop will also enable us to meet like-minded educators who are interested in LLL so that we can further develop projects such as this and increase the impact of our work and further research funding applications on a wider scale.

8 SUMMARY AND ACKNOWLEDGMENTS

We would like to acknowledge the EU Erasmus+ funding body and all partners and associated partners in the TRAINeng-PDP project (grant number: 2021-1-BE02-KA220-HED-000023151) for their help in this activity and report. Many thanks also to the academic staff who provided the module descriptors for analysis and external experts of the project, who reviewed the report.

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HELP THEM GROW: THE ENG-IST TOOL – SUPPORTING STUDENTS' PERSONAL DEVELOPMENT PROCESS TO STIMULATE LIFELONG LEARNING

Una Beagon, Aimee Byrne, Caitriona dePaor, Sofie Craps, Rani Dujardin, Lynn Van den Broeck Johanna Naukkarinen.

TRAINengPDP

Co-funded by the Erasmus+ Programme of the European Union
Grant number :
2021-1-BE02-KA220-HED-000023151

TRAINengPDP - Objectives

OB1 | Engage and motivate engineering students in their personal development process;

OB2 | Motivate and train lecturers to engage in the students' personal development process;

OB3 | Increase awareness about the competencies for LLL that are needed in engineering education & practice.

TRAINengPDP

www.fet.kuleuven.be/traineng

Lifelong learning (LLL)

= Progressively acquire, finetune, and transfer knowledge over long time spans while retaining previously learned experiences
(Parisi et al., 2019)

- MOTIVATION AND CURIOSITY TO LEARN
- CREATING A LEARNING PLAN
- LOCATING AND SCRUTINIZING INFORMATION
- SELF-MONITORING
- SELF-REFLECTION

(Cruz et al., 2020)

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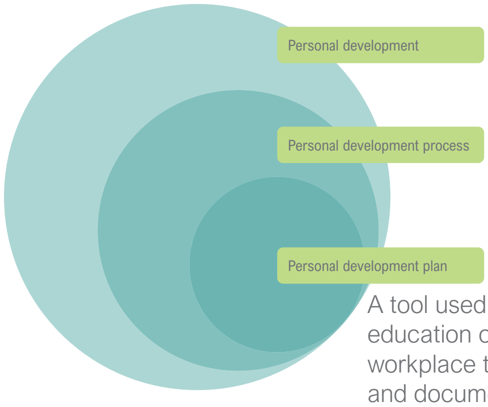
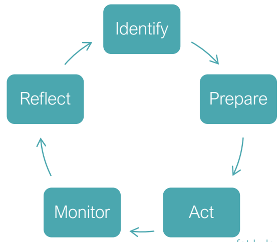
The personal development process (PDP)



= to develop as a person

- Formal or informal
- Knowingly or unknowingly
- Systematic or unsystematic



A tool used in education or the workplace to plan and document learning

TRAINengPDP

But how can we support students?

- Scoping review presented @ SEFI 2022: Lifelong learning as an explicit part of engineering programmes: What can we do as educators? – a scoping review
- Workshop SEFI 2022: The role of lecturers in engineering students' personal development process and promoting lifelong learning.

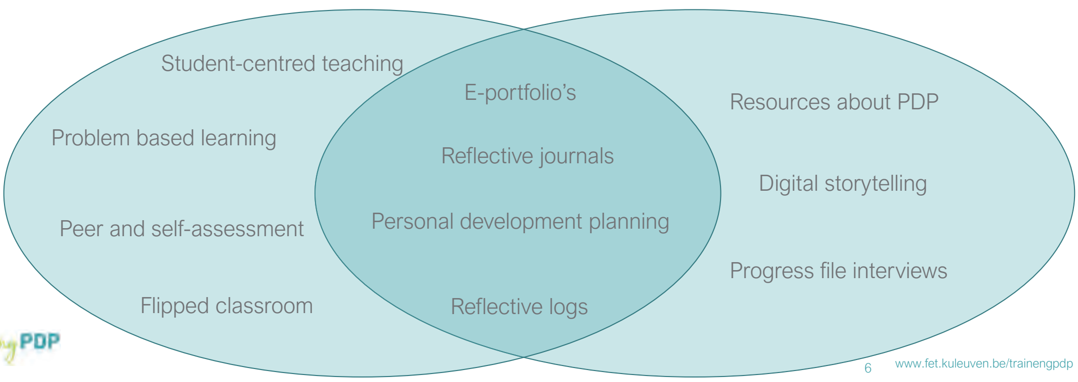
- Survey February 2023:
  - Gather good practices and general experiences
  - Capture lecturers' perceptions of their role in the students PDP

TRAINengPDP

PDP and LLL interventions

LLL interventions

PDP interventions



TRAINengPDP

Let’s start!

› Step 1: 5 mins – Complete Context Template

Think individually about a module you could use to implement an intervention.

› Step 2: 5 mins –

› Use the ENG-IST tool to select an intervention

› Step 3: Move to a table with that intervention

› Complete the template using the prompts:

› Identify, Prepare, Act, Monitor, Reflect

› Step 4: Feedback

TRAINeasyPDP


How can a Personal Development Process (PDP) be implemented in the curriculum?

1. Which module do you have in mind for this exercise?
2. How many students are in this module?
3. On which LLL competency or competencies would you like to focus?
   - ☐ Locating and scrutinizing information
   - ☐ Self-monitoring
   - ☐ Creating a learning plan
   - ☐ Willingness, motivation and curiosity to learn
   - ☐ Self-reflection
   - ☐ Not sure
4. What type of commitment do you expect from students?
   - ☐ One-time investment
   - ☐ Weekly low investment
   - ☐ In-class activities embedded in the course
   - ☐ Optional or voluntary commitment
   - ☐ Not sure
5. What would your involvement look like?
   - ☐ Limited: providing resources or giving instructions
   - ☐ In-class teaching or monitoring
   - ☐ Guiding individual students
   - ☐ Not sure
6. How much class time can you devote to this?
   - ☐ Little to none
   - ☐ A considerable amount of time
   - ☐ Not sure
7. How explicitly about PDP would you like the intervention to be?
   - ☐ Not explicit
   - ☐ Explicit
   - ☐ Very explicit with each step of the PDP clearly included
   - ☐ Not sure

Let’s start!

› Step 1: 5 mins – Complete Context Template

Think individually about a module you could use to implement an intervention.

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TRAINeasyPDP

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› Identify, Prepare, Act, Monitor, Reflect

› Step 4: Feedback

TRAINing PDP

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› Step 3: Move to a table with that intervention

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› Identify, Prepare, Act, Monitor, Reflect

› Step 4: Feedback

TRAINing PDP

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› Step 4: Feedback

TRAINing PDP

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   - ☐ Willingness, motivation and curiosity to learn
   - ☐ Self-reflection
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4. What type of commitment do you expect from students?
   - ☐ One-time investment
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   - ☐ Not explicit
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   - ☐ Very explicit with each step of the PDP clearly included
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Let's start!

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Think individually about a module you could use to implement an intervention.

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› Use the ENG-IST tool to select an intervention

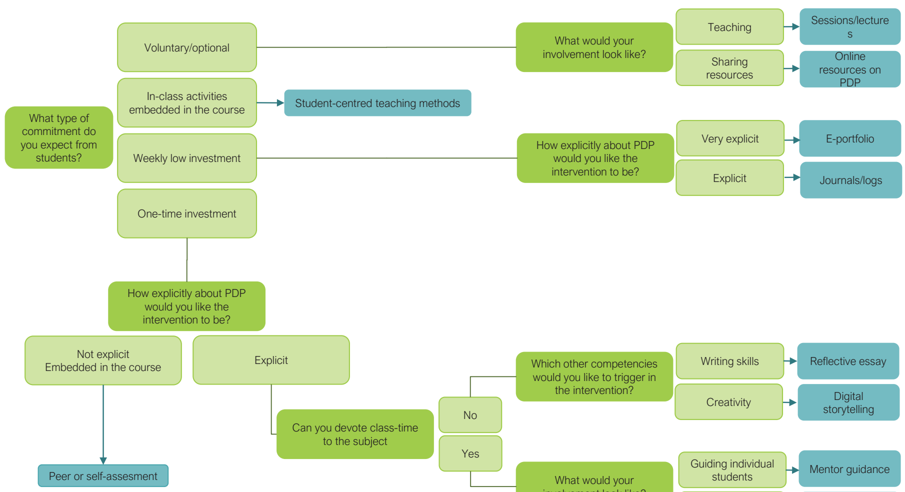
› Step 3: Move to a table with that intervention

› Complete the template using the prompts:

› Identify, Prepare, Act, Monitor, Reflect

› Step 4: Feedback

The ENG-IST Tool – A first version



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Let's start!

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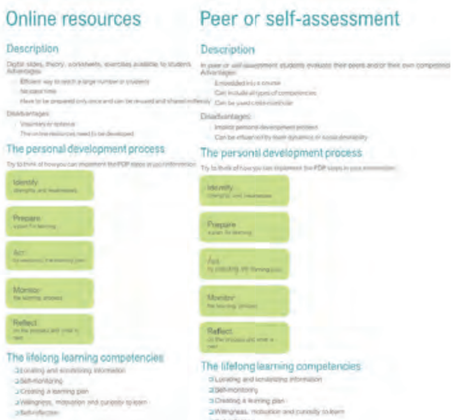
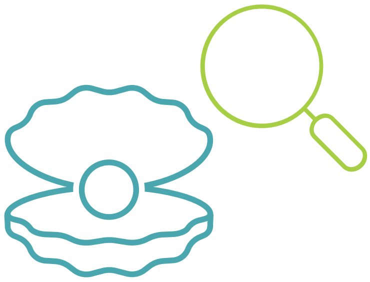


Interesting findings?!



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Grant number: 2021-1-BE02-KA220-HED-000023151

TRAINengPDP

Training engineers for lifelong learning through a personal development process

DUBLIN KU LEUVEN LUT University

INTERESTED IN OUR PROGRESS? FOLLOW US ON SOCIAL MEDIA

in trainengpdp

APPENDIX B – Notes and Feedback from Workshop Participants in specific interventions

Student-centred teaching

Description

In student centred teaching the focus of learning shifts to the student, for example PBL.

Advantages:

- Embedded into a course
- Training of many different competencies
- Already present in many programmes

Disadvantages:

- Implicit personal development process
- Usually a setting with already a lot of different elements, competencies and assignments

ADVANTAGES

- Meets the students where they are
- Aligns with employability skills
- Educator is made more aware of struggling students

DISADVANTAGES

- Different engagement based on student's prior experience could lead to loss of impact
- Attendance is required but could be weak

The personal development process

Identify strengths and weaknesses	-Use self and peer assessment and repeat after phases e.g. every 2 weeks. This allows for recognition of prior learning and allows the identification of knowledge gaps -Self-assessment regarding key competencies and group dynamics -Personality/teamwork test – what can everyone bring? Which perspectives? -Learning outcomes – SWOT focused on these -Content test (for maths) -Identify gaps in knowledge based on the learning outcomes of the module
Prepare a plan for learning	-Create a learning plan, Plan "how to learn" -SMART goals – how do you go about problem framing (who/what do you need?)? -Students use results from "identify" to set own goals -Topic analysis/surveys to identify needs gaps -Brainstorming -Co-create learning materials list (books, podcasts etc) -List how you currently learn and link this back to the personality test
Act by executing the learning plan	-Act on plan in class and collect material on how to approach the problem -Attend lectures -Video knowledge synthesis -Milestone reflections on goal achievement – logbook/journal online with weekly/ bi-weekly submission -Map of skills
Monitor the learning process	-Self-assessment on the Process itself. I.e. get them to reflect on how they performed in the self-reflection task via peer review -Test yourself, and compare to others / the teachers (teammates reflections, staff notes on submissions)
Reflect on the process and what is next	-Compare the problem frame and attitude towards complexity to start -Look to the future – what's next, and reflect on the learning process – what have they learned about complexity and positionality, can they set SMART objectives for the next academic year to then reflect on in may of next year -Have these students create the learning material for the new students as a starting point to help reflection and learning -Comparison / reflection on outcomes from "monitor" step

The lifelong learning competencies

- ❑ Locating and scrutinizing information
- ❑ Self-monitoring
- ❑ Creating a learning plan
- ❑ Willingness, motivation and curiosity to learn
- ❑ Self-reflection

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The e-portfolio (Group 1)

Description

An e-portfolio is an online tool to monitor progress throughout a longer period.
Advantages:

- Applicable to many different courses
- No class time except for a short introduction
- Short time investments from the student

Disadvantages:

- Need for an online platform
- Can be difficult to evaluate

Why did you choose the e-portfolio?

- The portfolio chose me (using the flowchart)
- We already use a basic portfolio (professional portfolio)
- It can be used to compile all experiences at the end of a programme and use them for job applications or to create a cv (= advantage)

A disadvantage: difficult to motivate students for a longer period of time. An essay f.e. is easier because you only have to motivate them once.

The personal development

Try to think of how you can implement the PDP steps in your intervention

Identify

- Job applications: rate yourself on competencies that are used in a job application that is interesting for you OR think about what skills you think an engineer would need and then compare to job applications.
- Use a map of competencies to let students choose a competency. This gives them more guidance (example from feelings).

Prepare

Prepare the learning activity

- Let them look for a course. Following the idea of using job applications, you can also work specifically with linkedIn courses
- Study plan, one action you are going to take

Act

Act on the plan

Importance of motivation

Monitor

Monitor the learning process

Reflect

Reflect on the learning process and what is next

- Go back to the job applications
- What have you learned from this course? Would you recommend it to the other students?

The lifelong learning competencies

- ❑ Locating and scrutinizing information
- ❑ Self-monitoring
- ❑ Creating a learning plan
- ❑ Willingness, motivation and curiosity to learn
- ❑ Self-reflection

The e-portfolio (Group 2)

Description

An e-portfolio is an online tool to monitor progress throughout a longer period.
Advantages:

- Applicable to many different courses
- No class time except for a short introduction
- Short time investments from the student

Disadvantages:

- Need for an online platform
- Can be difficult to evaluate

Advantage:
- You have a more explicit reflection of what students want and do, not only reflections of specific parts/competencies
- Creates option for individual learning

Disadvantage:
If you have an online platform, this is not a disadvantage. Tip : check https://mahara.org/

The personal development process

Try to think of how you can implement the PDP steps in your intervention.

Identify
strenghts and weaknesses

Prepare
a plan for learning

Act
by executing the learning plan

Monitor
the learning process

Reflect
on the process and what is next

- Identify crisis points, interview themselves
- Read job advertisements; identify skills a present it on posters. The posters can be on the walls so that the students can see these skills the whole time.
    - Link wih self-assessment
    - Link with the programme
- Look for actual events where something happened --> what could your role as an engineeer be?
- SWOT analysis: what are you doing now? What later?

- Prepare collect the plannings more on an individual basis

- Act/Monitor current gap. Need for advisors in the groups to monitor the process is often missing

- Reflection after the projects.
- Credits help to encourage the reflection process
- Works better if you can buikd further on previous projects
- Prepare portfolio's for (after) graduation

The lifelong learning competencies

- Locating and scrutinizing information
- Self-monitoring
- Creating a learning plan
- Willingness, motivation and curiosity to learn
- Self-reflection

Depends on the student. Is quiet subjective in most of the times due not well supported prepare/act/monitor phase

Reflective journals or logs

Description

Reflective journals or logs contain short reflective exercises throughout a longer period.
Advantages:

- Applicable to many different courses
- No class time except for a short introduction
- Short time investments from the ~~student~~ teacher

Disadvantages:

- Require sustained investment from the student
- Can be difficult to evaluate ← challenging indeed

General instructions:
Give language for identification / reflection
Create safe space & build trust
Give detailed instructions / examples
(especially when logs are a new thing)

The personal development process

Try to think of how you can implement the PDP steps in your intervention.

Identify
strengths and weaknesses

Use prompts (e.g. digital polling tools) to invite ideas and illustrate that there are no right and wrong answers
Have students interview each other → reduce the white paper syndrome

Prepare
a plan for learning

Connect to practical/concrete goals: pick one thing you want to develop

Act
by executing the learning plan

Monitor
the learning process

Reflect
on the process and what is next

Connect a reflective journal and a practical project → identify & prepare parts in a log & execution during a project, monitoring and reflection in a log

Johanna's afterthoughts:
Reflective journals seem to work well for the thinking part (identify, prepare, monitor, reflect) but might need some other framework (individual or group project, specific learning task etc.) to concretize and invite the action
Engineering students are not very used to expressing their thoughts on writing → good instructions and activity-based prompts useful to facilitate thinking

The lifelong learning competencies

- ❑ Locating and scrutinizing information
- ❑ Self-monitoring
- ❑ Creating a learning plan
- ❑ Willingness, motivation and curiosity to learn
- ❑ Self-reflection

Mentor guidance

Description

Mentor guidance is the individual coaching of students' personal development process.
Advantages:

- High intensity guidance is more likely to be effective
- Creates a closer relationship between lecturer and student
- Can be easier to address problems than in written form

Disadvantages:

- Large time investment from lecturer
- Requires specific competencies from the lecturer

The personal development process

Try to think of how you can implement the PDP steps in your intervention.

Identify strenghts and weaknesses	Questionnaires, peer assessments, +/- ambitions, norms, values, identity
Prepare a plan for learning	Create socially safe environment
Act by executing the learning plan	Students can share personal experiences, mentors step back and let students intereact
Monitor the learning process	
Reflect on the process and what is next	

The lifelong learning competencies

- ❑ Locating and scrutinizing information
- ❑ Self-monitoring
- ❑ Creating a learning plan
- ❑ Willingness, motivation and curiosity to learn
- ❑ Self-reflection

Role-playing exercise

Description

In role-playing students mentor each other on their personal development process.
Advantages:

- High intensity guidance is more likely to be effective
- Smaller time investment from the lecturer than with individual mentor guidance
- Can be easier to open up to a peer than to a lecturer

Disadvantages:

- Requires an effort from the students
- Difficult to assess

The personal development process

Try to think of how you can implement the PDP steps in your intervention.

Identify
strenghts and weaknesses

Prepare
a plan for learning

Act
by executing the learning plan

Monitor
the learning process

Reflect
on the process and what is next

1. Self-assessment (written format)
2. Group presentation about past experiences, strenght and weaknesses presenting which role they would prefer to play
3. Discussion and role assignment
4. Role assignment and periodical evaluation
5. Self-evaluation – written format

The lifelong learning competencies

- ❑ Locating and scrutinizing information
- ❑ Self-monitoring
- ❑ Creating a learning plan
- ❑ Willingness, motivation and curiosity to learn
- ❑ Self-reflection

Teaching Competencies

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Gothenburg, Sweden

Conference Key Areas: Fostering Engineering Education Research
Keywords: teaching competencies, abilities, workshop

ABSTRACT

In search of a model of teaching competencies for engineering education, we led a focus group discussion as a workshop at SEFI2023, where we got practitioners' perspectives on essential competencies for teaching. These were compared to a model of teaching competencies called the S2L model, developed and used at a technical university in Sweden. The aim of the workshop was to enrich the participants' understanding of which competencies are essential for teaching and to challenge and improve the S2L model. After the workshop, the competencies collected from the participants were analysed using content analysis. The results show that the teaching competencies suggested by the participants fit into the S2L model, giving the model support. The participants agreed that a model for teaching competencies is very useful for educators, for example, in self-development and when supporting new colleagues, as a checklist and a common language. They also expressed that the workshop had widened their views on teaching competencies.

1 INTRODUCTION

There is an ongoing discussion within the engineering education community about engineering competencies, i.e. the competencies our students need to develop. This is included as one of the themes of this conference, SEFI2023. In the same way, we argue that there is value in getting a better idea of what competencies we, the educators, need to develop. A description of teaching competencies can be a tool for developing engineering educators, for example, to identify individual needs for improvement and to contribute with a common language to use when talking about our development. It may also add perspectives in the process of identifying pedagogical competence, or lack thereof, when developing, promoting, or hiring staff.

Despite research showing that teachers' abilities are essential for student learning (Darling-Hammond 2006; Hattie 2008), there is no consensus on which the essential teaching competencies are. Is it that the teacher is able to listen to the students, that the teacher explains well, that the teacher uses modern methods and tools for teaching, or that the teacher can motivate the teaching methods in an informed way? Or is it that the teacher is very knowledgeable and shows love for the subject, that the teacher continues to develop, or all the above?

In an earlier study, we studied a model of teaching competencies, the S2L model, developed at Chalmers University of Technology in Sweden, where it is used both in a mentor program for new staff and as a basis for program development in a combined engineering and teacher education program (Bengmark nd). This study is a continuation of that study, in search of saturation of data, i.e. that new data does not add new perspectives, in this case, that it is consistent with the S2L model.

The research questions in this study are:

1. Are the essential teaching competencies suggested by the participant in this focus group consistent with the S2L model?
2. To what extent and in what way is a model of teaching competencies useful according to engineering educators?

We choose to frame the description of the teaching competencies as a scientific model. A scientific model, often called just a model, is a description that helps grasp some aspects of reality (Gerlee and Lundh 2016). As teachers of engineering subjects, we know how valuable and useful models are, despite being simplifications of the phenomenon. Models can be used for creating understanding, predictions, development, and a common viewpoint. These applications fit well with the goal of this research, which is to frame the essential teaching competencies.

2 WORKSHOP DESIGN AND ACTIVITIES

The aim of the workshop was two-fold: to enrich the participants' views of teaching competencies and to collect their opinions on the matter to develop and validate an existing model. After having stated these aims, we started the workshop by defining competency as follows. ”A competency is a human knowledge or skill that increases the individual´s ability to do what is sought”. Examples and non-examples of competencies were discussed. This was followed by the first activity, which was to individually list teaching competencies the participants see as essential in teaching, by drawing on their own teaching experiences. Each selected competency was noted on a separate sticky note. In groups of three to four, the participants then discussed and compared their noted competencies to clarify for themselves and the other group members what each chosen competency entailed. At the same time, the groups combined the individual answers into a joint compilation by grouping notes referring to the same competencies.

After this group work, the workshop leader presented the S2L model of teaching competencies as described below. The model was also briefly compared with other models from the literature (Darling-Hammond 2006; Niss 2003; Koehler and Mishra 2009). This comparison is not included in this text but can be found in the earlier study about the S2L model.

During the second activity, the workshop participants used the S2L model as a framework onto which they mapped the competencies their group had identified. This was done by placing their sticky notes on an A2 poster handed out at the workshop, where the model was illustrated. They were asked to give special notice to notes that they found hard to fit into the model, notes that would fit under several parts of the model, and areas of the S2L model that were left empty, i.e. without notes. The workshop continued with a common discussion about the relationship between the S2L model and the competencies suggested by the participants. Had the participants suggested teaching competencies that do not fit into the S2L model? Are there parts of the S2L model that are considered superfluous?

The third activity at the workshop was group discussions about why and when a model for teaching competencies can be useful. This was followed by a common discussion where all groups expressed their ideas while these were written on the board by the workshop leader.

The fourth and final activity was letting the participants self-estimate their teaching competency profile according to the S2L model in an anonymous digital poll and reflect on the aggregated result.

Fig. 1. The S2L-model for Teaching Competencies, consisting of nine sub-competencies grouped into three main competencies.

3 THE S2L MODEL OF TEACHING COMPETENCIES

We now give a short exposition of the S2L model of teaching competencies, more thoroughly described in (Bengmark nd). The model consists of nine competencies grouped into three main competencies, Subject Competency, Learning Cultivation Competency, and Leadership Competency, see Figure 1, which are described below.

Subject Competency has three sub-competencies. Firstly, there is Subject-internal Competency, which includes knowing facts, understanding concepts, being able to use procedures and methods, and problem-solving within the subject. Secondly, Subject-external Competency refers to the ability to use the subject knowledge in connection to other areas and the real world. Thirdly, Scientific Competency means knowing how evidence is formed, and how scientific methods are used to establish results within the subject. It also includes the ability to interact with other experts.

Learning Cultivation Competency has the following three sub-competencies. Assessment Competency is the ability to pinpoint the learners' current competencies and to extract knowledge on an aggregated level about common misconceptions. Design of Learning Competency is the competency to design learning activities in an informed way that affects the learners' competencies. The third is Explaining Competency, which is the ability to make the learning objects understandable, maybe by reformulating, visualising, or using metaphors.

Lastly, we have Leadership Competency, which also has three sub-competencies. The first sub-competency is Goal Competency, which is about choosing and formulating goals. Then there is Organisational Competency, which is the competency to create structures that enable the attainment of the goals. The last sub-competency, Influencing Competency, concerns the ability to make people strive, for example, by motivating and giving feedback.

The S2L model should be considered together with three related categories. These are not considered to be teaching competencies, although closely related (Bengmark nd). Two of these categories are fundamental in the sense that the teaching competencies build on them. The first is Personal Characteristics, which include features such as patience and kindness. The other is Collaboration and Communication Competency, which are general competencies of value in all of the three main competencies of the S2L model. The third and final category is Developmental Competency which includes the ability to improve your teaching competencies over time.

4 METHODOLOGY

We view this workshop as a focus group discussion, a qualitative research tool involving the participants in structured discussions, allowing an exploration of participants' perspectives and experiences (Gibbs 2012). The group consisted of 14 engineering educators active in various disciplines, making up a convenience sample as the participants voluntarily chose between parallel sessions during SEFI2023. The participants were told about the research on the S2L model and were informed and asked to withhold their data if they did not agree to participate in the research.

A structured discussion guide developed by the author was used. All questions posted and instructions given during the workshop were given both orally and on PowerPoint slides. The workshop leader facilitated the discussion, encouraged participants to share their thoughts and experiences, and probed for further elaboration when needed. The data collected consisted of essential teaching competencies suggested by the participants written on sticky notes and by writings of the workshop leader on the whiteboard during the common discussions, documented as photos after the workshop.

Content analysis (Krippendorff 2018) was used when analysing the suggested competencies, starting with the frame (Given 2008) consisting of the nine competencies in the S2L model together with the three related categories described above. Each item was considered for each of these categories. As each item was found to fit into one of the categories, there was no need for inductive categorisation.

The data from the discussion was structured and condensed on the board during the actual discussion and directly reported here. While not part of the research, we report on the self-assessment using simple descriptive statistics to characterise the participants and we also include representative comments about the participants' takeaway from the workshop.

5 RESULTS

The participants all together suggested 72 separate written items. Analysing their relation to the model gave results similar to those found in an earlier study. Seven of the items were about Subject Competency, 23 about Learning Cultivation Competency, and 24 about Leadership Competency. Two of the nine sub-competencies in the S2L model were not validated by the data, namely Subject-internal Competency and Scientific Competency. In a discussion at the workshop, the participant claimed that this omission was due to them taking these two sub-competencies for granted. Hence, this focus group valued all nine sub-competencies as essential.

Eighteen items that did not fit into the S2L model, but did fit into the three related categories described above. In the category Developmental Competency, we placed items such as *receive feedback*, and *learn from mistakes*. Into Personal Characteristics, we placed items such as *patient*, and *creativity*. The third and final set of items that did not fit into the model was related to Collaboration and Communication Competency, with items such as *communication*, and *teamwork*. Hence, the items suggested at the workshop did not identify gaps in the S2L model.

The workshop participants were enthusiastic about the usefulness of a common model or teaching competencies. The mentioned areas of use included self-development, and supporting the development of new colleagues. Participants pointed to the value of having a common language to use when talking about teaching competencies, maybe helping some realise that it is not only about subject knowledge and helping others not to forget to include leadership competencies. The participant also pointed to the usefulness of a model for teaching competencies when hiring new teachers, as a tool to broaden the perspective on what to discuss and look for.

In the anonymous self-assessment, the highest average was found in Design Competency with a mean of 4.5, where 1 meant very weak and 5 very strong. The lowest average and the biggest variation appeared for Scientific Competencies, indicating a wide range of scientific backgrounds among the participants.

Finally, when the participants were asked to anonymously write down their takeaway from the workshop, they were all positive about their enriched perspective, writing comments such as: *Very useful model that I would like to explore and use further*, and *Nice clear model for conversations around teaching*, *Thank you! This is a great framework to discuss teaching in a neutral manner and clearly highlight what we can do and what we're not so good at*, and *Very useful for my program. Better understanding of competencies and nice activity!*

6 CONCLUSIONS

The S2L model has earlier been studied in similar settings with almost 300 respondents in total. The data collected at this focus group discussion was consistent with the previous results, giving support to the model and indicating that we may have reached saturation in the collective data. We will continue to collect data to validate the models. However, our interpretation is that this model by now has sufficient support and is mature enough to be tested and used in practice by others. The example given by the participants of such practices includes using the model as a framework for self-development or collegial development. We hope that one of the next steps will include finding engineering educators interested in using the model in real-world settings, and in collaboration, study the model's usefulness in these applications.

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SUPPORTING TEACHERS IN CULTURALLY DIVERSE ENGINEERING CLASSROOMS: SHARING EXPERIENCES AND ACTIVITIES

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Keywords: *cultural diversity, engineering educators, internationalization at home, student activities, integration*

1 INTRODUCTION

An important aspect of working as an engineer is working in a global environment. Engineering education needs to equip students with this competence as ASEE, EURANEE and FEIAP have repeatedly stated (Handford et al. 2019). In addition, engineering campuses are increasingly international, both in terms of faculty and students. While there have been a number of pedagogical projects linking students with other countries either physically or online (through for example, COIL projects), which typically involves a relatively small number of students, there has been little research into maximizing the possibilities between ALL students on the home campus (Van Maele et al. 2021). This workshop aims to assist participants in formulating their own activities for the culturally diverse engineering classroom using inspiration from current tried and tested practices.

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For educational success and well-being, it is important that both domestic and international students can be integrated into campus activities, both inside and outside the classroom (Bergman et al. 2023). This purposeful integration can give students the intercultural competence skills that are much sought after in engineering graduates by companies (Hundley 2015). It is also a key objective of an internationalization-at-home strategy, commonly defined as "the purposeful integration of international and intercultural dimensions into the formal and informal curriculum for all students within domestic learning environments" (Beelen and Jones 2015, 69). While diversity can refer to a range of aspects (see SEFI n.d., Van Maele et al. 2023), this workshop focuses particularly on the culturally diverse student population. While this naturally involves the students' nationalities, this workshop sees nationality as only one aspect of a student's identity and acknowledges that other aspects can play an important part in students' interactions.

Teachers play a crucial role in the successful integration of these engineering students into the formal and informal curriculum, yet there is a lack of training provided for teachers in working with these culturally diverse groups in the classroom (Gregersen-Hermans and Lauridsen 2021). This workshop is thus part of a STINT funded project on educating the educators aiming to map existing professional development initiatives at Swedish higher education institutions and critically evaluate their effect for Internationalization at Home.

By the end of the workshop, participants:
-participated in a survey on their own and others' current internationalization-at-home activities;
-listed possible future activities to facilitate the culturally diverse engineering classroom applicable to their institutional setting;
-reflected on and discussed these activities in small groups.

2 WORKSHOP DESIGN

The workshop was divided into two parts: (1) setting the scene and (2) teaching activities in the culturally diverse engineering classroom.

Part 1: setting the scene
The first part of the workshop consisted of three parts:

1) **Introductions / definitions:** Facilitator-led introductions and definitions of diversity and internationalization-at-home (IaH).
2) **Questionnaire:** Participants shared their own experiences and practices in their own culturally diverse teaching environments, using a brief and trialled questionnaire on internationalization at home activities (Weimer et al. 2019). The results of this questionnaire gave an overall picture of current activities and practices being carried out at participants' institutions
3) **Shared activities:** The facilitators shared some examples of their own activities from their home universities as well as reactions to some of these activities from faculty members (from the results of a survey and ongoing interviews). The activities included setting up the international classroom and

following up mid-course, particularly concerning a purposive use of intercultural group work.

Part 2: teaching activities in the culturally diverse engineering classroom
The second part of the workshop consisted of two parts:

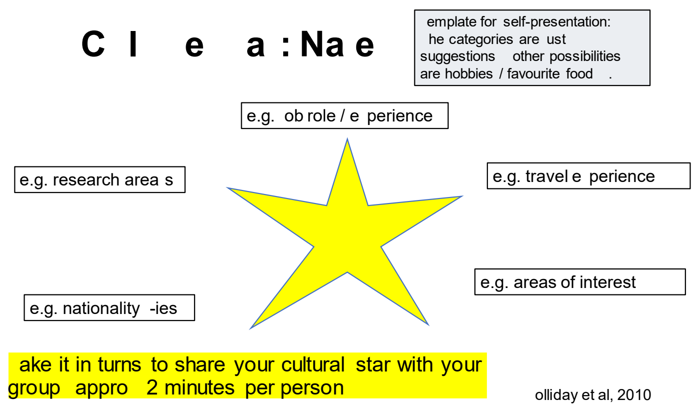
1) **Brainstorming** ideas individually
2) **Sharing** ideas in small groups of four

3 RESULTS

The workshop focused on three main activities, as shown below.

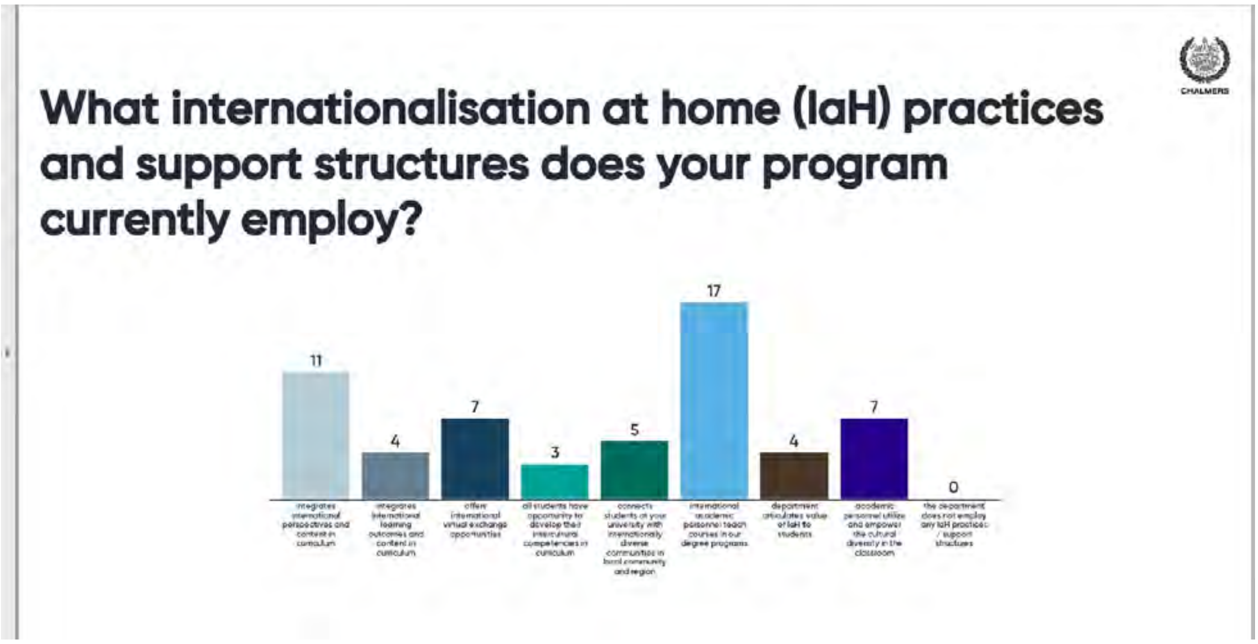
Activity 1: Cultural star

A crucial aspect of working in the international classroom is getting to know each other beyond country and discipline labels. Participants shared their own cultures through sharing their cultural stars with each other (Holiday et al. 2017, 238-239):



Activity 2: Internationalisation at Home survey

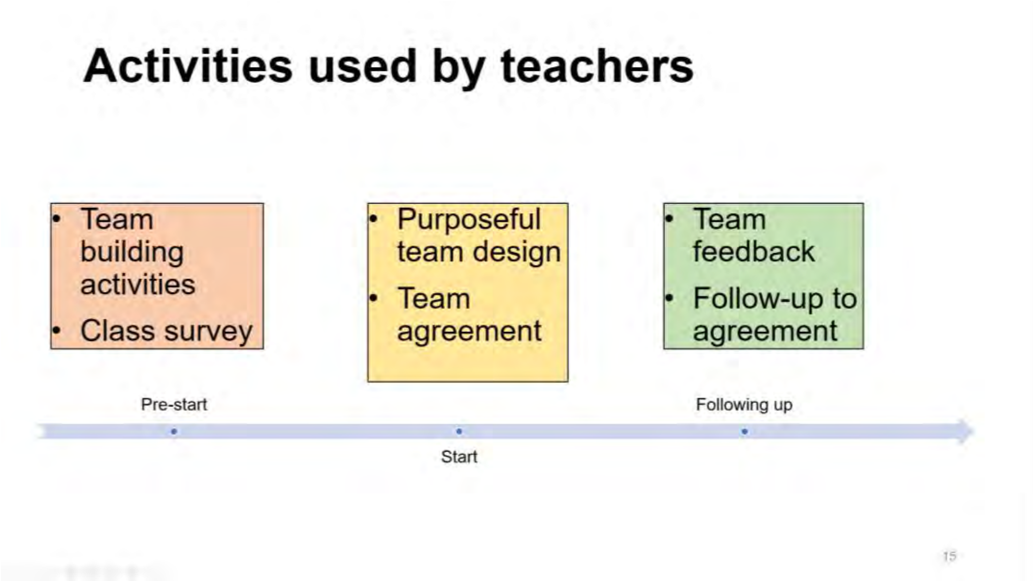
This mentimeter survey (mentimeter.com) provided an overview of the internationalization-at-home practices employed by the participants at their own universities (as far as they were aware).



The results from the 17 participants showed that the most common internationalization-at-home practice was that of having international academic personnel (17 votes) followed by integrating international perspectives and content in the curriculum (11 votes) and academic personnel utilizing and empowering the cultural diversity in the classroom (7 votes) as well as offering international virtual exchange opportunities (7 votes). However, since the mentimeter lacked a scale, it was difficult to show the extent to which this was being applied, and it was commented that in some cases, this was rather minimal.

Activity 3: Sharing of activities

In small groups of four, the participants then shared their own examples of possible activities to use in the culturally diverse classroom based on the figure shown below. In the figure, activities are grouped according to whether they took place before the course starts, at the start of the course or at some point later in the course. Many participants exchanged experiences of team building activities as a way to bring culturally diverse groups together.



4 CONCLUSION

While many participants felt that little was being done at their own institutions to work with culturally diverse students, the activities showed that some commonly used activities such as team forming and building or getting-to-know-you activities can contribute positively to bridging the gap that can often exist. In addition, a more conscious use and focus on existing resources such as the presence of international staff and working with international perspectives can also facilitate internationalization-at-home.

5 ACKNOWLEDGMENTS

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How to make calculus assignments *not* boring? Designing calculus assessment with the constructive, contextual, collaborative, and self-directed principles of problem-based learning

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1 MOTIVATION

Engineers use science, technology, and math to solve problems. Usually, engineering students take calculus, a core discipline in engineering programs, as one of their first mathematical courses. This course lays the required mathematical foundation for classical engineering courses such as thermodynamics, kinematics, and fluid mechanics, mathematical follow-up courses, such as systems theory and control, differential equations, and mathematical modelling, as well as fashionable topics, such as data science and artificial intelligence. Bluntly, there are three key tools in calculus: limits, derivatives, and integrals. As learning outcomes, engineering students need to learn how to use these tools for simple exercises and to apply these tools in a broader context to improve their problem solving skills. However, as one of the most challenging courses in engineering programs (Biza et al. 2022), students have difficulties mastering these learning outcomes. One reason could be the traditional teaching and learning methods that are still often employed for these basic courses, neglecting the fundamental principles of Problem-Based Learning (PBL) in course design and delivery (Freeman et al. 2014).

2 OBJECTIVES

This workshop aims to introduce the attendees to 1) the PBL system implemented at Maastricht University and 2) our vision on assessment, which includes *meaningful assessment* and assessment being in line with the *constructive*, *collaborative*, *contextual* and *self-directed* (CCCS) *principles* of PBL (EDLAB 2023). We illustrate these ideas through three short examples of assessments developed for a calculus course in the BSc Circular Engineering at Maastricht University. In the second, and larger, part of the workshop, attendees will have the opportunity to explore how they can apply these concepts to the assessment components in their courses through a PBL way. In particular, the intended learning outcomes (ILOs) are: 1) attendees can **describe** the PBL paradigm and the CCCS principles; 2) attendees can **recognize** the CCCS principles in assessments of other courses; and 3) attendees can **implement** the CCCS principles in their own course assessments. These courses do not necessarily have to be mathematical courses!

3 BACKGROUND AND RATIONALE

PBL at Maastricht University (UM) is a student-centered teaching method that promotes active learning and critical thinking (EDLAB 2023). While various implementations exist, the essence of PBL revolves around four key learning principles: constructive, contextual, collaborative, and self-directed learning (Dolmans 2019). Constructivism emphasizes the activation of prior knowledge and building new knowledge on top of it. Collaboration focuses on working together in small groups to share knowledge and perspectives. Contextualization highlights the importance of understanding the real-world context in which problems arise. Self-Directed Learning encourages students to take ownership of their learning process, set goals, and monitor their progress. Teachers act as facilitators, providing guidance and feedback rather than solely relying on frontal teaching. This approach will produce graduates with strong problem-solving skills, critical thinking abilities, and the ability to work in diverse teams (Anggraeni et al. 2023, Boelt et al. 2023).

One of the fundamental principles of the UM vision on assessment is that the assessment is *meaningful* for the students' learning process, meaning that the evaluation should provide relevant and valuable feedback to both student and teacher. In addition, assessment should align with the learning objectives and activities. Meaningful assessments should be fair, unbiased, and transparent, providing clear criteria and standards for evaluating performance. It also implies authentic assessments designed to resemble real-world situations and tasks closely. Authentic assessments help students develop skills relevant to their future careers and provide them with a sense of the relevance of their learning. Teachers can also use the information to adjust their teaching strategies and improve the effectiveness of their instruction.

4 WORKSHOP DESIGN

The workshop consists of three activities plus a pre- and post-workshop assignment. Materials for all activities can be downloaded via this link: https://surfdrive.surf.nl/files/index.php/s/K5FaMlkoxvrW1yx. In the pre-workshop assignment, we ask participants to prepare a case by thinking about a possible assessment that they currently use in their course or an assessment that they wish to (re)design for their course according to the CCCS principles. In order to prepare the case properly, we provide a one-page template in the workshop materials, which can be found via the aforementioned link. Additionally, attendees receive a terminology list for PBL and CCCS concepts and a description of three assessment examples from a calculus course to help them prepare their case. Completing the pre-workshop assignment prior to the onsite workshop is beneficial for the workshop experience of the participant *and* other participants, but completion is not mandatory and does not limit participation in any way.

During the workshop, we briefly cover the pre-workshop assignment in the first part (10 minutes) to ensure all attendees have the same understanding about the basic concepts (ILO1). In the second and largest part of the workshop (40 minutes), attendees participate in an interactive and collaborative exercise where they attempt to recognize the CCCS principles in their assessment or explore strategies to implement the CCCS principles by discussing in small groups (ILO2+3). During this process, the workshop organizer will provide guidance and feedback. In the final part (10 minutes), we will discuss several ideas in the plenary session.

In the spirit of open education, the post-workshop assignment provides the attendees with the materials to organize a similar session for their colleagues to facilitate further development and innovation as well as to continue the discussion after the workshop. As part of the post-workshop assignment, we ask the participants to fill out an evaluation form to assess the quality of the workshop and to reflect on the CCCS principles as a guiding tool for designing their own assessments.

The workshop design nicely reflects the PBL-style because attendees gain knowledge by combining prior knowledge and new experiences (constructive) through small-group discussion (collaborative) about assessment components from their courses (contextual) with an organizer that acts as a guide on the side instead of a sage on the stage (self-directed). The workshop is an extension of existing in-house educational events for teacher training programs and continuous development programs.

The workshop targets STEM teachers, who want to learn to integrate PBL and CCCS principles in their practice. Participating in the workshop requires no prior knowledge about calculus nor about PBL and CCCS. Participants are encouraged to complete the pre-workshop assignment that provides all relevant information prior to the workshop.

5 SIGNIFICANCE FOR ENGINEERING EDUCATION

The CCCS principles are relevant design principles for engineering education as they can ensure proper alignment with the goals and demands of the engineering profession. Constructive learning emphasizes that learning is an active process where students gain knowledge by combining prior and new knowledge, which are essential engineering skills. The ability to collaborate effectively is critical for engineers, and the PBL approach, which emphasizes collaboration, can help students develop this skill. Contextual learning is particularly relevant for engineering as many engineering problems are context-specific and require understanding the broader socio-technical context. Self-directed learning is essential for engineers as it fosters lifelong learning and professional development. Furthermore, literature seems to indicate positive student perceptions for a variety of PBL activities and educational programs w.r.t. generic skills (Boelt et al. 2023).

6 RESULTS OF THE WORKSHOP

The workshop attracted 14 participants that focus on engineering education, but have diverse backgrounds: engineers, mathematicians, physiscist, etc. They were also of diverse academic positions, such as PhD, post-doc, professor, lecturer, etc., but also company employees such as Mathworks.

The participants took a short survey (N = 14). They rated the following statements from 1 to 5 where 1 means “I strongly disagree and 5 means “I strongly agree.”

Statement	**Rating**
The workshop was useful to me.	4.3
I learned something about PBL/CCCS.	4.1
I will use the CCCS principles in my teaching.	4.0
I will probably run the exercise again with colleagues.	3.3

In the open feedback section of the survey, the participants indicated that they especially appreciated the concrete examples of assessment methods designed using the CCCS principles as they provide a source of inspiration for their own practice. They also enjoyed the hands-on nature and the exchange of experiences in the open discussion setting.

Two points of improvement were also suggested: examples in other disciplines (than math) and a more diverse grouping of participants during the collaborative exercise.

7 CONCLUSION

This workshop enhances engineering education knowledge by providing participants with a framework to describe, recognize, and implement the CCCS principles in their courses. The workshop format encourages dialogue among participants, fostering the exchange of ideas and best practices in engineering education. The post-assignment allows further discussion beyond the workshop.

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ENGINEERING EDUCATION RESEARCH: WRITING FOR PUBLICATION (WORKSHOP)

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Conference Key Areas: *Fostering Engineering Education Research*
Keywords: *Engineering Education Research, Journal, Publishing, Authoring*

ABSTRACT

In this interactive workshop, facilitated by a team of editors from the *European Journal of Engineering Education (EJEE)*, the *Journal of Engineering Education (JEE)*, and *IEEE Transactions on Education*, participants had the opportunity to network with other scholars in the field, and learn about the journal publication process and how best to navigate it.

It served as an informal opportunity for scholars at all stages of their publication journey to share their experiences, both positive and negative, directly with each other and journal editors. Participants co-created a document of shared insights about writing for publication, the key outcomes of which are presented in this paper.

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1 BACKGROUND AND RATIONALE

The process of getting an article published in an academic journal can be difficult to navigate. Authors typically wonder what editors and reviewers seek, how to focus their manuscripts, and how to expand conference papers to a level acceptable for journal publication.

Understanding academic journals and finding the appropriate journal for one's contribution to the field of Engineering Education Research can improve the academic publishing experience for all. Given that these are skills which we can and need to develop as researchers, this workshop aimed to provide an overview of the academic publishing process to make this process transparent and attainable. Discussion helped stimulate reflection and hone key writing skills, whilst providing everyone with the opportunity to share their experiences helped foster a supportive community.

2 WORKSHOP DESIGN

This interactive session aimed to support authors (new and experienced) in developing knowledge and understanding of academic journals and effective manuscript writing practices to facilitate publication. Whether a student, Early Career Researcher, or established researcher, participants in this workshop found a space to discuss experiences and challenges, as well as generate strategies for future submissions.

The workshop began with introductions from the facilitators, enabling participants to "see the humans behind the journals".

2.1 Workshop outline

We followed the agenda outlined below.

- Welcome and Introductions – Getting to know each other (facilitators and participants).
- Think-Pair-Share/Quickfire Discussion – What is the best aspect of authoring? What would you like to know as a new author? What is the most daunting aspect of authoring?
    - Collating "what you would like to know" and "what is most daunting" to seed discussion in the next activity
- Group Discussion with each group facilitated by an editor - Strategies for authoring (focused by the outcomes of the initial group discussion regarding daunting aspects of authoring)
    - Break-out groups collaborate on an online shared document to collate and distill workshop discussions and insights
- Synthesis – Discussion of results from each group.
- Wrap Up and Top Tips from the Editorial Teams.

Through these dialogues, participants co-created an enhanced understanding of strategies for success in academic publishing. Key takeaways from the workshop included expanded networks from having worked with a variety of scholars and journal teams, and the co-created document with workshop insights, summarised below.

3 RESULTS OF THE WORKSHOP

The initial discussions around what authors would like to know and what they find most daunting resulted in the following themes being identified within the room.

What would you like to discuss?

- Transitioning into the engineering education field
- Managing different or conflicting advice from different reviewers
- When you don't understand the reviewer comments - what do you do?

What is most daunting?

- Long timeframe for feedback from reviewers
- Changing discipline - learning new language, ways of writing, disciplinary norms.
- How to select the "right" journal in which to publish
- Do you really have to read 15 books on each concept to be able to publish - when is enough, enough?
- Avoiding predatory journals

These points were then discussed in small groups within the room, and four key areas emerged from the feedback: writing, choosing a journal, the submission process, and the review process. Discussions focused on strategies for authors. Key outcomes of these for each area are presented below, written as advice to you, the reader.

3.1 Writing

It is important to find and own your own writing process, this process will not be the same for everyone.

It is easier to write a manuscript with a journal already in mind (see next section) so that you can prepare your scoping and structure so that it aligns with the journal requirements.

To get started, structure your argument outside of the journal format using, for example, a whiteboard, slide presentation, or mind map. This can help you focus in on what you really want your manuscript to say and how to structure the narrative of the manuscript so that there is a logical flow for the reader. Another idea is to create your journal paper on a page (e.g., create a bullet point as a guide for writing each paragraph in more detail) and iterate between that outline and the broader work (for example by using the Mumford method).

It is also important to remember that you do not need to present “all the ideas” in one manuscript; consider what piece you can add to the conversation.

3.2 Choosing the journal

Choosing a journal to submit your work to can be daunting (this was agreed upon by all at the workshop), some guiding questions to ask yourself are:

a) What conversation do you want to join? What conversations in the field do you want to shape?
b) Papers that are exciting to you - where were they published?

With these questions answered you can think about the framing and audience of different journals. It is important to understand the scope and remit of journals differs and you should keep this in mind when choosing a journal for your work. For example, EJEE is looking for usefulness and scholarliness, whereas JEE focuses on scholarliness. You can also begin to look for special issues that your work aligns with and information on upcoming special issues will be available on journal webpages.

3.3 Submitting your work

Write a cover letter to the Editor. If you are a new researcher, declare this in your letter to the editor when submitting work. For our field, you should also:

a) Make sure you have a theoretical framework.
b) Make sure to write what your methodology is and that it is aligned with your research aims.
c) Write clearly and concisely.

3.4 Dealing with reviewer comments

There are a range of decisions that you may receive following submission of your manuscript. In general, these are: Reject, Major Revision, Minor Revision and Accept.

In all cases, you will receive feedback. Understand that this is an opportunity, the more feedback you receive and integrate, the better the final result.

Also keep in mind that rejections are common. This doesn’t mean that it is a pleasant experience for anyone, but please be assured that it is not only you. You will be provided with feedback from the editorial team and reviewer comments if the manuscript was sent for review.

If you receive a decision of either Major or Minor Revision, you will be provided with feedback from the editorial team as well as reviewer comments. You will be provided with a deadline for submitting your revised manuscript. A misconception that was uncovered during the workshop is thinking that the author of a manuscript must make all the changes suggested by the reviewers. This is not necessarily the case and whilst incorporating reviewer advice should enhance the clarity and quality of the manuscript, there may be times when an author has a justified reason for not implementing a suggestion made by a reviewer. Whilst this is perfectly acceptable practice, it is important that you provide your rationale in your response to the reviewers in a polite manner “Thank you for the point, we considered … but because (e.g., length and scope) …”.

Like authors, the reviewers are human; we all bring our unique perspectives to the work we do. Therefore, it is entirely possible for you to receive conflicting reviewer feedback. Although guidance should be provided by the Associate Editor in this case, there may be times when discussing the feedback with senior colleagues is useful in helping you to determine how to best address the feedback. Editors are typically happy to discuss potential ways to address wide ranging feedback so please do remember that you can contact them for guidance.

If a reviewer recommends something that is already in your manuscript, this may mean that they do not understand what you have written and so it may need explaining or rewording. Keep in mind that if reviewers are struggling to understand something, readers will probably be in the same situation, and so more clarity is probably needed.

We editors hope that you will never receive “mean” feedback, as we strive for our journals to provide advice that is professional and constructive. That said, it is easy to read any level of criticism harshly. Emotions are heightened when feedback is provided on work we are passionate about. Remember, firstly that reviewers are volunteers who are typically doing their best to help you strengthen your message, and secondly that it helps to take a break and reflect on the feedback when you return. One piece of advice is to take a two stage approach to enable you to process reviewer comments; open and read the reviewer comments, then put them aside for a week before opening them again. Again, you may want to discuss the comments with a trusted colleague to gain additional perspectives.

4 SIGNIFICANCE FOR ENGINEERING EDUCATION

This workshop was offered to help demystify the publication process for prospective authors and to broaden the pool of potential contributors, making engineering education research more accessible for the increasingly diverse community engaged in this field. In turn, by hearing from this broader pool of contributors, the editorial teams from leading journals gained insights into the perspectives and experiences of new authors embarking on their academic journeys, as well as hearing perspectives from more established authors. The key points they identified during the workshop are:

1. Read a lot and notice good writing.

Read papers from the journal you are considering submitting your work to. Read your own work carefully, checking for coherence throughout the manuscript.

2. Understand the process.

Reviewers make a *recommendation*; *editors* make the decisions. Reviewers make *suggestions* for the development of the manuscript; these are not orders. Make a table with responses to the reviewer comments to upload with the revised manuscript, be grateful for the good advice and explain politely, where applicable, why you chose not to follow a suggestion.

3. **Become a reviewer.**

Picking the right reviewers is important and leads to a better experience for both reviewers and authors. Having a larger pool of reviewers helps this process and becoming a reviewer is also useful for developing your understanding of the publication process, especially for new authors. Becoming a reviewer provides you with an opportunity to see the process from the reviewer’s perspective.

5 ACKNOWLEDGEMENTS

The authors would like to thank all the participants for their rich discussions and contributions during the workshop.

SUSTAINING ENGINEERING EDUCATION RESEARCH: SHARING QUALITATIVE RESEARCH DATA FOR SECONDARY ANALYSIS

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Conference Key Areas: *Fostering Engineering Education Research, Equality Diversity and Inclusion in Engineering Education (Research)*
Keywords: *Research Methods, Qualitative Research, Secondary Data Analysis*

ABSTRACT

The need for secondary data analysis practices emerges from multiple sources. Qualitative researchers often have rich data sets that far exceed the time available for data analysis, and many of us wish that someone could spend more time with the data. We also recognize that local data sets would benefit from further analysis that linked our data with related data collected in different contexts. Many also grapple

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with increasing data sharing requirements from funding agencies that raise concerns about participant confidentiality and data integrity. This workshop provides a chance to explore potential responses to these concerns through a robust dialogue around secondary data analysis practices and pitfalls.

1 MOTIVATION AND LEARNING OUTCOMES

1.1 Motivation

The need for secondary data analysis practices emerges from multiple sources. Qualitative researchers often have rich data sets that far exceed the time available for data analysis, and many of us wish that someone could spend more time with the data. We also recognize that local data sets would benefit from further analysis that linked our data with related data collected in different contexts. Many also grapple with increasing data sharing requirements from funding agencies that raise concerns about participant confidentiality and data integrity. This workshop provided a chance to explore potential responses to these concerns through a robust dialogue around secondary data analysis practices and pitfalls.

1.2 Learning Outcomes

As a result of this workshop, participants should now be able to:

- describe what secondary data analysis (SDA) encompasses;
- identify potential challenges and opportunities with SDA;
- explore if, and under what conditions, one or more of their existing or planned data sets might be amenable to SDA;
- identify concrete steps needed to make data available to other researchers for collaboration using SDA and/or to work with data from other researchers.

2 BACKGROUND, RATIONALE, AND RELEVANCE

Qualitative researchers often collect extensive data sets encompassing hours of interviews and observations, much of which often remains underexplored. But tapping the rich potential of these data sets has thus far been challenging despite ongoing calls for data sharing by funding agencies. Concerns about ethics, participant confidentiality, misuses of data, and more are compounded by disciplinary and publication practices that value original data over integrative efforts based on secondary analysis. Additionally, institutional reward structures may discourage the kinds of collaborations needed for data sharing. As a result, changing the paradigm of single-use data collection requires actionable, proven practices for effective, ethical data sharing, coupled with sufficient incentives to both share and use existing data. At the same time, globally, qualitative research continues to be a challenging paradigm for new researchers, especially those transitioning from technical engineering research (e.g., Dart, Trad, and Blackmore 2021; Gardner and Willey 2018), and learning qualitative methods requires time and guidance. To address these and other issues, this workshop draws on findings from a U.S.-based project (Paretti et al. 2023; Case et al. 2023) on secondary data analysis (SDA) to stimulate dialogue with a broader international group of participants that explores what SDA is, why and under what conditions participants do or might make their own data available for SDA, and what philosophical considerations and practical steps are involved in such data sharing.

Notably, discussions of secondary data analysis, though not widespread in our field, are not new. Our work in this area integrates and extends previous conversations such as those presented by scholars from a range of countries and contexts in a 2016 special issue of Advances in Engineering Education (e.g., Johri, Vorvoreanu, and Madhavan 2016; Trevelyan 2016; Walther, Sochacka, and Pawley 2016). In our own recent work (Paretti et al. 2023), we have used the work of two pilot teams to identify the benefits and challenges of collaborative SDA as a means to build capacity and engage new scholars into engineering education research. This work has allowed us to build a framework for collaborative SDA that honours the time and effort of both participants and original researchers, while making space for new scholars to engage with existing data in new ways. Prior to SEFI, however, this framework had not been explored in international contexts, where both regulations and ethical practices related to human subject research can vary widely.

3 WORKSHOP DESIGN

Because SDA is not a one-size-fits-all endeavour, this workshop was designed to help participants think more creatively, expansively, and critically together about the role of SDA in engineering education research. The timing and content of this 60-minute workshop was as follows:

5 minutes	Overview: Working definition of SDA, followed by a brief explanation of our overall SDA project goals and national context.
10 minutes	National Contexts: Input from audience members to identify national/regional contexts and policies surrounding data sharing.
5 minutes	Pilot Project Results: Guiding practices and challenges that have emerged from two pilot projects conducted over the past year.
15 minutes	Small Group Discussion • What existing data sets do you have that could be amenable to SDA? What opportunities does SDA offer for that data? • What challenges does SDA pose for that data? • How do national regulations impact your data sharing practices?
15 minutes	Reporting out from Small Groups and Discussion
10 minutes	Next Steps: Opportunity for networking across institutions and contexts to identify potential SDA partnerships.

4 RESULTS OF THE WORKSHOP

The workshop was attended by 30 participants representing 16 countries (11 in Europe as well as Australia, China, Qatar, South Africa, and the U.S.). More that half of the participants were working in contexts where data sharing was either mandated or strongly encouraged, and approximately half had prior experience with secondary data analysis.

The workshop facilitators shared the emerging, as but as yet unpublished, framework developed in the U.S. to guide collaborative secondary data analysis, tentatively labelled SHARE, with key principles formulated as follows:

- **S**tewarding collaborative relationships
- **H**onoring the context of data
- **A**ligning questions and data
- **R**esponsibly reusing data
- **E**xpanding capacity and ownership

This framework (more details in a forthcoming publication) is designed to address the ethical and practical issues related to sharing data for secondary analysis. It seeks to protect and benefit both the original researcher(s) and the study participants, while simultaneously creating opportunities for new and experienced researchers to engage with and make meaning with rich, robust existing data sets.

Workshop participants agreed that both data sharing and secondary data analysis held high potential value for sustaining and growing the engineering education community. Concerns that surfaced in the workshop echoed those that have emerged from previous discussions (see Johri, Vorvoreanu, and Madhavan 2016; Paretti et al. 2023), including the difficulty of de-identifying qualitative data in ways that protect participant confidentiality while still providing sufficient context to support later analysis and the more general challenge of understanding the context of data one did not collect. In particular, this international conversation surfaced the key issue of national context related to engineering education (e.g., how higher education is funded, how students select or are selected to universities and majors, the ages at which students are tracked into majors, and more). In addition, concerns specific to the European General Data Protection Regulation (GDPR) emerged that bear further investigation. In the US, for example, Institutional Review Boards (IRBs) regulate research at an institutional level. The EU-wide GDPR is a wide-ranging set of regulations (not aimed specifically at university research) that came into place in 2018, with significant legal penalties for non-compliance, and universities are still working through some of the implications. In this context where primary data collection is already fairly complicated and subject to multiple restrictions, it does seem that SDA will present particular challenges. Similarly, among European researchers in particular, questions arose centred on participants' concerns about the monetization of data and increasing reluctance to provide broad consent for personal data to be used beyond a narrowly constructed set of aims.

As anticipated, then, the workshop elicited critical national variations in research contexts that make data sharing and secondary data analysis challenging both within and across national borders. At the same time, participants all recognized the need for and value of such work if it can be done in ways that are ethical and attentive to the needs and interests of all parties.

5 SIGNIFICANCE AND ATTRACTIVENESS

Data sharing, and thus secondary data analysis, is increasingly important globally as a result of national policies as well as deepening interest in comparative and cross-national work, but it remains challenging for qualitative researchers concerned about a range of ethical and practical considerations. Engaging in this dialogue through a workshop at SEFI enabled us to foster a more global conversation and engage with researchers working in contexts where debates and policies on data sharing and open access are more advanced. This deeper international conversation has enabled us to explore possibilities for data sharing beyond national boundaries to support equity and sustainability in our global community. It has also guided our further thinking on the development of the SHARE framework as we consider when and where the framework can have value to the field. At the same time, the workshop enabled participants to think in more detail about the possibility of SDA with their own existing data, as well as consider how and where they might engage in SDA in partnerships with other researchers whose data is available for such work.

6 AUDIENCE

Our workshop included experienced and novice qualitative researchers interested in learning more about data sharing practices and secondary data analysis. While some participants were familiar with SDA and/or had data they were considering sharing, others were at much earlier stages of their research careers. The workshop introduced key terms and ideas and create space for participants to look at data sets to evaluate if, when, and how SDA might be appropriate.

7 ENHANCEMENT OF KNOWLEDGE AND DIALOGUE

As requirements for data sharing increase globally and rich qualitative data sets remain underexplored in researchers' own archives, discussions about secondary data analysis are increasingly important. How, why, and under what conditions we engage in analysis of data collected by other researchers are essential questions for our field. By fostering broad dialogue around these issues, sharing insights from our own work, and learning from practices and projects developed by others, the engineering education community can build intentional, carefully considered knowledge about ethical, effective, and meaningful secondary analysis in our field. Participants left with a potentially actionable framework for conducting collaborative SDA, examples of when SDA may and may not be appropriate, and a clear sense of their responsibilities either as the original researchers or those coming to an existing data set.

8 ACKNOWLEDGEMENTS

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LGBTQ+ Safe Zone Ally Workshop

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Conference Key Areas: *Equality Diversity and Inclusion in Engineering Education*
Keywords: *LGBTQ+, inclusivity, allyship*

ABSTRACT

Lesbian, gay, bisexual, transgender, and queer (LGBTQ+) individuals have historically faced harassment, exclusionary behavior, and discrimination in many aspects of their lives, including in educational settings. This workshop will equip participants with the knowledge and tools to (1) recognize the negative impact of bias and heterosexual/cisgender privilege on the experiences of LGBTQ+ individuals; (2) recognize challenges faced by LGBTQ+ individuals in STEM fields; (3) identify strategies for creating an inclusive and affirming environment; and (4) formulate a plan to become an ally for LGBTQ+ individuals. The workshop is open to students, faculty, and the professional community in STEM fields and assumes a basic understanding of LGBTQ+ concepts and terminology. By becoming Safe Zone allies, STEM professionals can help create a more diverse and talented engineering workforce and promote diversity and inclusion within the field.

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1 MOTIVATION AND LEARNING OUTCOMES

Despite significant progress in LGBTQ+ rights and representation in recent years, individuals who identify as LGBTQ+ still face discrimination and marginalization in many areas of society, including in educational settings. In higher education, studies have shown that LGBTQ+ students are more likely to experience harassment, exclusion, and a hostile campus climate than their heterosexual peers (Rankin, Weber, Blumenfeld, & Frazer 2010). Research also indicates that a negative campus climate can impact the academic performance, mental health, and overall well-being of all students, particularly those from marginalized groups (Greathouse et al. 2018). Therefore, creating an inclusive and supportive campus climate is essential for the success of all students.

As STEM fields have historically been male-dominated and heteronormative, LGBTQ+ individuals in these fields often face unique challenges and barriers to achieving equality. Thus, our abbreviated Safe Zone workshop aims to address the following learning outcomes:

1. Recognize the negative impact of bias and heterosexual/cisgender privilege on the experiences of LGBTQ+ individuals.
2. Recognize challenges faced by LGBTQ+ individuals in STEM fields and recognize how engineering culture can act as a barrier to inclusion and equality.
3. Identify strategies for creating an inclusive and affirming environment for LGBTQ+ individuals on college campuses.
4. Formulate a plan to become an ally for LGBTQ+ individuals.

2 BACKGROUND AND RATIONALE

The concept of Safe Zone workshops can be traced back to the 1980s and the LGBTQ+ community's fight for equal rights and recognition. During this time, some universities and colleges began establishing LGBTQ+ resource centers to provide support and resources for LGBTQ+ students, faculty, and staff. However, these centers were often insufficient to create a safe and inclusive environment for LGBTQ+ individuals on campus.

The Safe Zone program, which originated in the 1990s, has been successful in creating an inclusive campus environment for LGBTQ+ individuals by training faculty, staff, and students to be allies and advocates for the LGBTQ+ community. The program has since been adopted by numerous institutions, with Safe Zone ally training and institutional policy changes affecting a gradual positive change in climate for LGBTQ+ individuals (Mack 2014).

Despite these initiatives, progress in STEM departments has been slower than in other disciplines (National Academies of Sciences, Engineering, and Medicine 2019). Research has shown that aspects of STEM culture serve as impediments to advancing LGBTQ+ equality in our disciplines, which translates into a chillier climate for LGBTQ+ individuals in STEM (Cech 2013, 2015; Cech & Waidzunas 2011).

Therefore, there is a pressing need to create more Safe Zone allies in STEM who can recognize and mitigate the barriers faced by LGBTQ+ individuals in these fields. Our proposed workshop aims to equip participants with strategies for creating a more inclusive and affirming environment for LGBTQ+ individuals in STEM departments and beyond.

3 WORKSHOP DESIGN

This workshop is designed using best practices (LGBT Resource Professionals) to achieve changes in attitudes, knowledge and supportive behaviours of STEM professionals toward LGBTQ+ students and colleagues. The one-hour agenda includes topics related to:

1. Heteronormativity, bias, and heterosexual/cisgender privilege
2. Aspects of engineering culture that serve as a barrier to inclusion and equality for LGBTQ+ individuals
3. Strategies for creating an inclusive and equitable environment for LGBTQ+ students and professionals
4. Formulating a plan to become an LGBTQ+ ally

Prior to the workshop, participants will receive a primer on basic LGBTQ+ concepts and terminology. Workshop activities will promote understanding and empathy and provide opportunities to practice responding to bias. At the end of the workshop, participants will use what they have learned in the workshop to formulate a plan to become an active supporter of LGBTQ+ students and colleagues.

4 SIGNIFICANCE FOR ENGINEERING EDUCATION AND ATTRACTIVENESS OF THE WORKSHOP TOPIC

Safe Zone ally training can help create a more inclusive and supportive learning environment for LGBTQ+ students, faculty, and staff. Like many other STEM fields, engineering has historically been less welcoming to LGBTQ+ individuals, and they may face challenges such as discrimination, harassment, and marginalization. Consequently, LGBTQ+ students and professionals are more likely to leave STEM than their non-LGBTQ+ peers (Cech & Waidzunas 2021; Hughes 2018).

By participating in this workshop, engineering educators can gain a deeper understanding of the challenges that LGBTQ+ individuals may face in their academic and professional careers and learn strategies to create a more inclusive and supportive environment. The workshop will help practitioners to identify and challenge their own biases and assumptions and provide them with the tools to create a welcoming and affirming environment on campus.

Achieving a critical mass of Safe Zone-trained professionals can help engineering schools and departments send a message that they are committed to promoting diversity and inclusion within the field. This can positively impact the recruitment and retention of LGBTQ+ students, faculty, and staff and contribute to creating a more diverse and talented engineering workforce.

5 TARGET AUDIENCE & PARTICIPANT KNOWLEDGE REQUIRED

This abbreviated Safe Zone Ally Training is an interactive, research-informed workshop for students, faculty, and the professional community. The workshop content and materials have been developed and refined by a community of STEM professionals specifically for a STEM audience. The workshop assumes a basic understanding of LGBTQ+ concepts and terminology around sex, gender, and sexual orientation. Participants will be provided with a resource in advance of the workshop to review these concepts.

6 ENHANCEMENT OF KNOWLEDGE AND DIALOGUE ON THE WORKSHOP TOPIC.

Safe Zone workshops are interactive training sessions intended to raise awareness for LGBTQ+ inclusion in STEM and create a visible network of allies to foster a supportive atmosphere for LGBTQ+ individuals. Our abbreviated Safe Zone workshop will provide participants with an awareness of biases and assumptions that may affect interactions with LGBTQ+ individuals. Participants will also learn how to recognize discrimination and privilege and the impact they have on the experiences of LGBTQ+ individuals. In addition, the workshop will explore the specific aspects of engineering culture that can act as barriers to LGBTQ+ equality in STEM fields.

Through interactive activities and discussions, participants will develop empathy and understanding of LGBTQ+ experiences and learn tangible strategies for creating a more inclusive and affirming environment for LGBTQ+ individuals in STEM departments and beyond. By becoming Safe Zone allies, participants can contribute to a campus culture that values diversity, fosters inclusivity, and supports all students' intellectual and social development. A post-workshop survey will be sent to capture participants’ insights and feedback.

7 ACKNOWLEDGMENTS

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SUPPORTING STUDENTS FROM DIFFERENT EUROPEAN UNIVERSITIES AND BACKGROUNDS TO IMPROVE ACADEMIC AND SOCIAL OUTCOMES: THE EUNIWELL MASOEE PROJECT WORKSHOP

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***Conference Key Areas**: Engineering skills and competences, Lifelong learning for a more sustainable world, Equality diversity, and inclusion in engineering education*
***Keywords**: social mobility, disadvantaged students, skills, sustainability, enterprise*

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1 INTRODUCTION

There is a notable discrepancy between the relative prosperity of Europeans and the global security and sustainability challenge. The mission of the ERASMUS+ 2020 European University for Well-Being (EUniWell) alliance is to address this. Our project, “Maximizing Academic and Social Outcomes in Engineering Education” (MASOEE) interprets this contradiction for engineering educators, exploring how to ensure graduates make the utmost contribution to societal wellbeing by narrowing attainment gaps. We are combining the expertise of British, French, Italian, and Swedish faculties to identify, share, and ultimately transfer best practices for professional, business, and sustainability skill teaching that is aligned to the EU competency frameworks including EntreComp (Bacigalupo et al. 2016) and GreenComp (Bianchi, Pisiotis, and Cabrera Giraldez 2022). Furthermore, we are finding out how disadvantaged cohorts in each partner faculty are characterized and supported. The project is guided by the following research questions:

- What are the similarities and differences between our students, staff, teaching, and culture?
- How are skills taught and embedded in programmes? What are student attitudes to learning these? How do we currently define and measure social outcomes?
- Which new approaches can we employ improve social and academic outcomes?

2 WORKSHOP DESIGN

We began the workshop by providing participants with an overview of the MASOEE project, sharing our aims, approaches, and activities. We also explored the types of disadvantages experienced by students and STEM based professionals, noting the impact at three main points: pre-engineering studies, during engineering studies, and post-qualification whilst establishing their career (Kricorian et al. 2020; Moscoso 2022; Royal Academy of Engineering 2023). We worked collaboratively with the participants to better understand how students developed their competencies as well as understanding how disadvantage is understood within the context of their own institutions. The workshop allowed participants to reflect on and improve the academic and social outcomes of their students. The learning outcomes were:

- To compare a diverse range of strategies for undergraduate learning of engineering in the themes of technical skills, entrepreneurial skills, professional skills, and sustainability skills.
- To understand more about the learning needs of engineering students from a diverse range of less advantaged backgrounds and explore ways of modifying curriculum and culture to better meet these needs.

Following the initial introduction of the project, the remainder of the workshop was divided into three activities presented to users on the whiteboard (Figure 1): an empathy map to explore disadvantaged students within each participant’s context (left); a diamond nine activity to prioritise the skills most needed by students from a disadvantaged background (right); and brainstorming activity to explore ways of teaching of these skills could be improved focussing on innovative pedagogies (bottom). Each activity was led by a specific MASOEE team member.

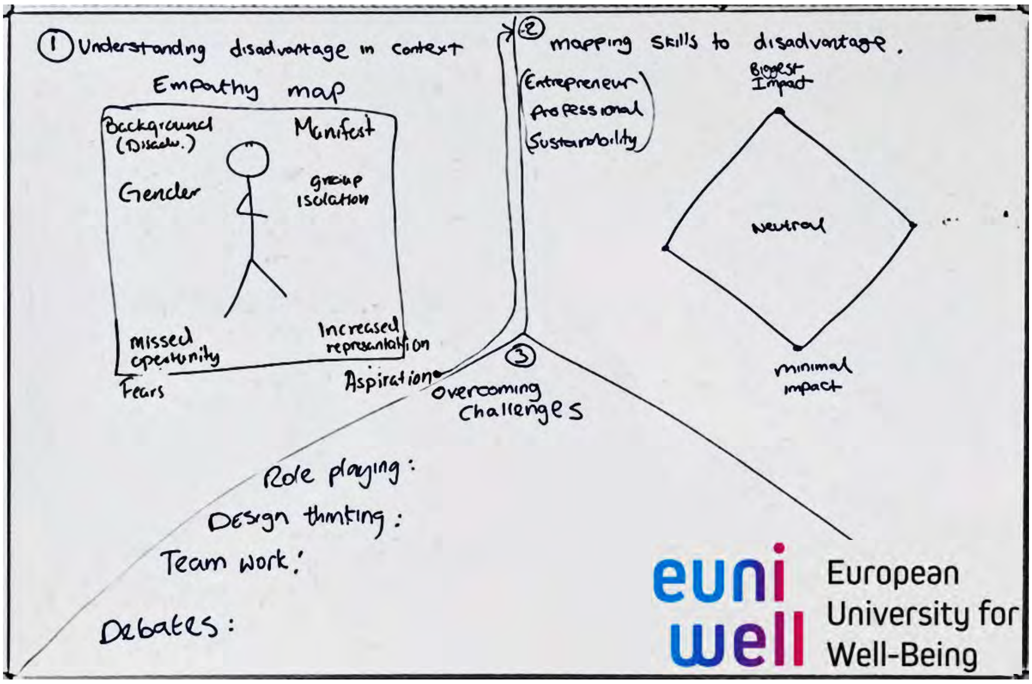

Fig. 1. Whiteboard activities: empathy map, diamond 9, and overcoming challenges.

For the empathy map, the participants were asked to explore characteristics of a disadvantaged student, using the map to scaffold their discussions. The empathy map focussed on four main areas - 'Background' (type of disadvantage), 'Manifest' (how the disadvantage may physically manifest itself), 'Fear' (the impact of the physical manifestation of disadvantage), and 'Aspiration' (what the students strive to achieve). For the subsequent Diamond-9 activity, participants were asked to consider emerging engineering skills in the area of entrepreneurship, professional, and sustainability, and how the skill acquisition of the disadvantaged student profiled in their empathy map would be affected the most and least, with lists of skills in this area being used as prompts. The final activity – overcoming challenges – was to look at those skills with the biggest impact together, with the empathy map, and discuss how emerging pedagogies might be used to help students overcome their fears, reduce their manifest, and fulfil their aspirations. These pedagogies included role playing, design thinking, teamwork, and debates. After the activities concluded, the project team summarised the workshop discussions.

3 RESULTS

18 participants attended the workshop from several countries including Austria, Belgium, Germany, Ireland, Italy, and United Kingdom. They were divided into 2 groups, with a mixture of countries represented within each group to ensure diversity of experience.

3.1 Empathy Map

3.1.1 Background

People in group 1 identified four areas of disadvantage that they felt had the potential to impact their students' aspirations: language, prior education, family support, and learning disabilities. They agreed it is important to reflect on the intersectionality of each area, which led to animated discussions on the implication for students with more than one area of disadvantage. In contrast, people in group 2 identified eight areas of disadvantage: economic, social, cultural, colour, gender, language, internet access, and disabilities.

Notably, each highlighted language barriers and disabilities as a potential impediment to successfully accessing engineering as a discipline. One female in group 2 shared their own lived experience, noting: "When I started, we were three females in a 100 class – it felt like it was hard to belong". Other female group members agreed and reflected that this had inhibited their ability to work within a team or complete a group assignment and consequently develop skills development. However, a male group participant queried whether this feeling would impact female engineers materially; sharing his own lived experience of seeing women take part in successful teams and groups, often assuming leadership roles. Despite this positive observation, female participants felt that overall females are disadvantaged.

3.1.2 Manifest

Building on prior discussions around background, both groups explored how disadvantage may physically present itself. Group 1 linked directly back to the areas of disadvantage that they had listed under 'Background':

- Language - students may miss or misunderstand information.
- Prior education - students may lag behind, feel shame, or disengage.
- Family support - students may miss out on jobs, coaching, or networking if their family does not have a background in a similar professional area.
- Learning disability - students may difficulties with certain areas of academic life e.g., organisation.

Group 2 reflected more generally on the physical impact of disadvantage, noting that struggling students may suffer worsening mental health, including feelings of isolation and shame.

3.1.3 Fears

These physical manifestations of disadvantage may lead students to develop a negative outlook, with group 1 identifying fears students may have, such as lack of confidence ("I'm not good enough"), Feeling overwhelmed, questioning themselves ("Why am I doing this?"), or experiencing feelings of inferiority ("I don't belong").

3.1.4 Aspirations

The groups discussed the types of aspirations that students from disadvantaged backgrounds may have. Group 1 reflected on aspirations which directly negated the fears: "I am good enough", "I want to succeed", and "I will be accepted". In contrast, group 2 linked aspirations directly to professional aspirations such as becoming a chartered engineer thereby increasing their social status.

3.2 Diamond-9

The second activity aimed to map skills to areas of disadvantage, utilising a 'Diamond 9' frame as a scaffold. An interesting point observed by the team during this activity, was how each group understood the initial questions presented to them. Group 1 prioritised the backgrounds of disadvantage identified in the first activity, sharing that they felt that "prior education" and "language" had a neutral impact on the students' ability to learn, whilst "Learning disabilities" and "gender" (specifically female) were deemed to have minimal impact.

Group 2 identified four areas of competency then linked these back to their previous work on the empathy map in terms of type of disadvantaged background and how this may manifest for each student:

- Professional skills - linked to mental health.
- Communication - linked to language.
- Defining Problems - linked to isolation.
- Leadership - linked to social, cultural, colour, gender, language, and disabilities.

For this group, professional skills had the biggest impact on a student's ability to learn, followed by communication whereas defining problems and leadership were placed closer to neutral. Again, gender was a topic of discussion, with some disagreement over whether it should be included. There was some agreement on it being a positive in terms of sustainability because a mixed group might potentially have a broader perspective.

3.3 Overcoming Challenges

For the final activity participants brainstormed ways to overcome the challenges students face stemming from their disadvantaged backgrounds. While we presented the groups with four key aspects: role-play, teamwork, debates, and design thinking, both groups decided to add more. Group 1 proposed culture, community, and programme scaffolding. Group 2 added role models specifically targeted to underrepresented groups. Role-play garnered a mixed response. Group 1 suggested that it might be unpopular, while group 2 saw the benefits in students acting other roles would benefit communication and leadership skills.

Both groups agreed that teamwork was beneficial if properly prepared and supported. This included ensuring groups were gender diverse, effective mentoring of teams, and monitoring to prevent passenger behaviours (students not actively participating). Group 1 believed that design thinking might pose challenges in terms of its applicability to future jobs; the groups didn't identify a direct link to help disadvantaged students. Group 2 viewed 'Debates' as a valuable opportunity for students to enhance their communication skills.

4 SUMMARY

The workshop provided a stimulating exercise for engineering educators to consider disadvantaged students by characterising them in an empathy map. This schema allows us to explore how disadvantage might impact skills acquisition, and also how students’ aspirations might be a useful driver in designing pedagogies to narrow attainment gaps and foster social mobility. A key insight we had while running the workshop was that by considering disadvantage as unfulfilled aspirations, and the aspirations themselves as negated fears, as engineering educators we might be more inclined to address different forms of disadvantage through common means, potentially benefitting those students whose disadvantages receive less attention than others’.

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WHO, WHAT, HOW? TACKLING SKILLS CHALLENGES: FUTURE RELEVANCE, STAKEHOLDER DIFFERENCES, AND TEACHING HURDLES: THE ENGINEERING SKILLS SIG WORLD CAFÉ

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Conference Key Areas*: Engineering Skills and Competences, Lifelong Learning for a more sustainable world, Innovative Teaching and Learning Methods*
Keywords*: skills, competencies, challenges*

ABSTRACT

The Engineering Skills Special Interest Group (SIG) ran a workshop on the current challenges in teaching engineering skills. This workshop employed the “world café” participatory method where attendees visited three tables for a structured discussion with a member of the SIG. Each table posed a different question: On the What? table we discussed which skills are most relevant for future practitioners. The Who? table focussed on the differences in the way that various professional skills are conceptualised by main stakeholders. Finally, at the How? table we discussed the facilitators and barriers in designing and delivering skills education. The outcome of the workshop presented here is a mapping of skills in terms of present and future importance to attendees and their countries, and a classification of stakeholders in terms of macro, meso, micro level when considering their influence over skill conceptualisation and realisation.

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1 INTRODUCTION

Our goal is to teach a diverse cohort of engineering students who will bring a variety of perspectives to the profession. This will result in more inclusive and creative engineering products, services, and solutions. We must teach a growing number of emerging technical competencies in areas like immersive technologies, digital twins, additive manufacturing, visual analytics, cyber security, AI, and systems complexity. Moreover, employers place increasing value upon professional skills which compels us to teach these too.

Accelerating our need to better teach professional skills is the emergence of a new technical competence – Artificial Intelligence. While this will significantly transform the way engineers design, optimise, and innovate solutions while applying their critical and analytical technical acumen, it also highlights the need for engineers to develop those people-centric skills which are less likely to be replaced with chatbots, solvers, and content generators. These skills include empathy, emotional intelligence, teamwork, interdisciplinary, lifelong learning, critical thinking, cultural awareness, ethical sensitivity, social responsibility, and the innovation and entrepreneurship mindset.

'Skills' are often interchangeably referred to as competencies, outcomes, and attributes. This can result in contradictory views as to what is meant by skill, how skills are taught and developed, and how students demonstrate proficiency; each engineering education stakeholder has their own definitions. Consequently, we hit several barriers when instructing students. These include unclear motivation, pedagogical shortfalls, institutional inertia, perceived lack of space in curricula, and fear of a negative response.

2 WORKSHOP DESIGN

This 1-hour workshop was hosted by members of the Engineering Skills SIG on 5/9/23 at the SEFI 2023 conference. There were twenty participants (Figure 1) who had the opportunity to discuss and learn about the current challenges we encounter to teach engineering skills. We ran the workshop using the "world cafe" participatory method to share knowledge, build relationships, and discuss current ideas. The room was split into three areas for groups of up to seven persons to informally discuss these questions with a member of the SIG. There were three consecutive 15-minute rounds of conversion so that attendees visited every area in the café, each focusing on one of these topics:

- **What**? We discussed which skills are most relevant for future practitioners because we maintain exhaustive skill inventories which might be considered unwieldy. For example, the EU EntreComp framework (Bacigalupo et al. 2016) has 15 competences along an 8-level progression model! Therefore, a key motivation was to consider ways to rationalise inventories and make them more comprehensible. To develop effective educational activities for mature students with limited resource, it might be imperative to define and agree on a few key skills required to develop early in a technical career.
- **Who**? We focussed on the differences in the way that various professional skills are conceptualised by main stakeholders: professional engineering institutions, engineering educators, employers, and students. Such differences can be problematic. For example, disparities in the way that educators and industry perceive a skill can result in ineffective teaching interventions which do not

develop graduates to the degree expected by employers (Meier, Williams, and Humphreys 2000). We discussed how such issues might be resolved. Participants were asked to give examples of skills mismatch and resolution strategies.

- **How**? We discussed the facilitators and barriers in designing and delivering skills education. These factors included designing an appropriate curriculum and its activities, educating students on the broad range of competencies, and assessment. For example, how can we solve the "reflection paradox" to satisfy the requirement for students to describe, evaluate, and develop their professional skill learning (Hermsen, Van Dommelen, and Hueso Espinosa 2022)? Since STEM students, in general, are more focused on technical issues, discussions were also directed towards how they can be motivated to improve their self-awareness, soft skills, and self-management skills to launch a successful career in the technology market.

Attendees left the workshop with insights into different understandings and meanings of skills and competencies, which professional skills that are valued by educators from different disciplines/countries, the differences in conceptualising skills by different stakeholders, facilitators, and barriers in designing and delivering skills education, and their capabilities to teach and assess professional skills. In this workshop paper we present results from the What and How table.

Fig. 1. Participants

3 RESULTS

3.1 Most important and unimportant skills

In the What? table, three groups successively contributed a piece of the puzzle; the first group mapped the most important technical (figure 2) and professional (figure 3) skills, defined by the SIG in 2021, drawn from the literature. Each member of the group selected the three most important engineering skills, motivating the selection and contextualizing with respect to the specific engineering field and country. The second piece of the puzzle was provided by the second group, to identify the least important engineering skills i.e., those that are perceived less relevant and crucial for engineers. Similarly, to the first group, each member selected the three least important skills, motivating and contextualizing the answer by specifying field and country. Finally, the third piece of the puzzle was about the future: each member of the third group was asked to predict the most relevant skills for the next ten years

and also suggest possible missing skills in the reference map in this forward-looking perspective.
There are several findings from the resultant mapping. Across all engineering fields, professional skills are becoming increasingly relevant, especially communication. Interdisciplinary, collaborative working and responsible action continue to increase in importance. Among the technical skills, systems thinking, and integration are identified as especially relevant, again independent of the engineering discipline. Technical skills in the area of augmented and virtual reality as well as data and cyber network security are considered relevant to computer science, and that the respective skills should not necessarily be taught in other engineering programmes. Interdisciplinary, collaborative work, and ethical and social responsibility emerged as critical professional skills for the future, similarly artificial intelligence was the most selected among the technical skills. It should be noted that the results should be further generalised, as the majority of data was collected from UK academics. Ways to establish a more diverse dataset should be considered including not only academic from a variety of fields but also students and industrial partners. This could potentially be done through a future SEFI online seminar. Or, as a starting point, by collecting data in the institutions of the SIG members. Once we identify more generally the skills required in the future a seminar should be organised for all relevant stakeholders.

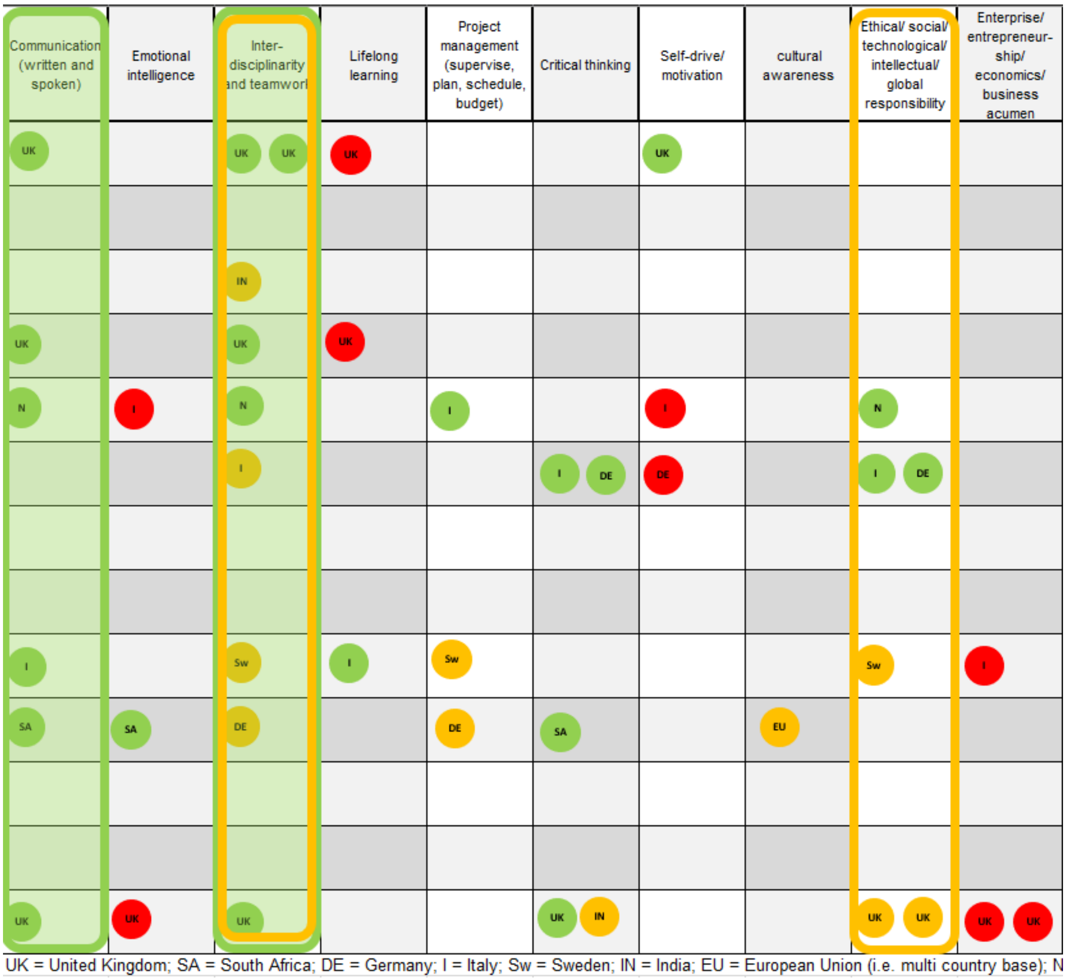

Fig. 2. Professional skill mapping to attendees/countries

Fig. 3. Technical skill mapping to attendees/countries

3.2 Macro, Meso, and micro-level skill conceptualisation

At the Who? table, participants mapped the key stakeholders who influence the way in which skills are conceptualised within their own European context at a macro, meso and micro level. The stakeholder identified are:

- Macro: PEIs, accreditation bodies, government policy and strategy, skills reports, education strategy, international market forces, media.
- Meso: Institutional strategy, local industry and local government/regional strategy, students unions.
- Micro: module teams, students and student body, programme directors.

Key stakeholders were found to vary by context. For example, in Norway, union bodies are considered to play an influencing factor. In comparison, the government was considered as having limited influence in Spain. Similarly, the degree to which student financing and quality measures, and ranking systems influenced curriculum was seen to vary. In addition to this, the job market and industrial sectors varied between countries. Participants then considered how these stakeholders influence the conceptualisation, inclusion, and development of specific skills starting with examples of sustainability and communication. Participants referred to Lewin's force field analysis (Kuhn 1951), in which change processes are characterised as a state of imbalance between driving forces (e.g., new personnel, changing markets, recent technology) and restraining forces (e.g., individuals' fear of failure, organisational inertia). The influencing factors involved varied significantly between contexts and between the two skills considered. The 'trickle down' of influences at a meso level (e.g., strategy) to a micro level (e.g., teaching in the classroom) also appear to vary considerably depending on both national and institutional context. A summary of the key findings is given below:

Sustainability was impacted at the macro level.

- Sustainability is often part of government and/or institutional education strategy as well as accreditation criteria (and by implication industrial recommendations). In some cases, the strategy is not communicated or resourced, leading to surface level approaches being taken.
- There is increasing student pressure to include sustainability in the curriculum. Courses must remain relevant, and sustainability can be used as a marketing tool (Byrne 2023)
- Students and staff often conceptualise sustainability as including environmental aspects whilst neglecting societal and, to a lesser extent, economic aspects.
- Some academics may not want to teach sustainability in depth as it takes away from technical content. In contrast, some educators may increasingly focus on sustainability research, the findings of which may be embedded in modules.
- In some contexts, sustainability encompasses equality, diversity and inclusion (EDI), ethics, cultural awareness, and recognition of global and interdisciplinary imperatives. This increased recognition is influenced by evolving societal imperatives, including among universities themselves, and across corporate workplaces, which promote associated industry imperatives around graduate attributes.

Communication was thought to be influenced, at the meso and micro levels.

- Communication skills are consistently considered as lacking within skills reports. However, these reports lack depth.
- The difference in engineering education and what is required in practice, e.g., adaptability, communicating to those at different level, nuanced communication when embedded in a community with its own actors, each with their own experience frame and role within the hierarchical structure, community expectations and unwritten rules such as frequency of reply, need to write emails, notes, memos, meeting summaries.
- Educators may avoid teaching communications skills due to student resistance/feedback.
- Educators may prioritise technical over 'soft' skills.
- Educators may tend to focus of communication styles similar to those used within scientific journals.
- Concerns around quality and rigour of assessment may lead to educators failing to focus on informal communication such as email, memos, meeting notes.
- We cannot fully replicate communication in the classroom and assessment due to the complex need to communicate with multiple people across expansive network, and the situated nature of communication in the workplace.

Participants said the exercise was useful in identifying the many factors that influence engineering student skill development. The method has potential for use as a comparative tool and will form the basis of future work within the SIG.

4 SUMMARY

By definition, the continual evolution of the engineering skill set will always be an active topic. This workshop created an opportunity for educators, through a structured discussion, to appreciate the different priorities given to skills, and to recognise the various stakeholders who influence the skills agenda. There was a high level of agreement about the relevant importance of emerging professional and technical skills, as well as an increased awareness of how different skills depend on a different subset of stakeholders. Future SIG work will consider how to bring this "what, who, and how" structured approach to a wider audience.

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Workshop: Promoting Engineering to K12 students through Spatially Challenging Making and Outreach Activities

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***Keywords**: Spatial ability, STEM outreach, Maker education, K12 Engineering, Design-based learning*

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ABSTRACT

Outreach activities are an important and valuable approach to promoting engineering education and careers to young people. They provide an excellent way to show that engineering can be fun, challenging and rewarding. With some careful thinking, they can also be used to promote and develop spatial ability, a cognitive ability that is very important to engineering. The purpose of this workshop is to demonstrate examples of outreach activities that are the result of such careful thinking. Those who attend this workshop will be able to:

1. Explain why and how spatial ability is so important to success in engineering education
2. Summarise findings from research on gender and SES differences in spatial ability
3. List some key features of hands-on outreach activities that require spatial thinking
4. Find and explain a lesson plan or set of instructions to run a spatial outreach activity
5. Suggest ideas for how they could adopt spatial thinking into their outreach activities

1 INTRODUCTION

Along with verbal and mathematical abilities, spatial ability is a primary factor of intelligence. Large scale longitudinal studies (e.g., Wai, Lubinski, and Benbow 2009) have shown spatial ability to be a more important than mathematical ability in influencing the selection of engineering as a career for young people. This has at least two implications for outreach activities that have an engineering content or theme. First, young people with low spatial ability may struggle at a cognitive level to engage with and succeed in these activities and may not find them to be as fun, challenging and rewarding as the instructors assume. If paired with a high spatial ability child who easily grasps the process and quickly completes the activity, a low spatial ability child may feel incompetent. The outreach activity may backfire and teach these low spatial children they are not suited to engineering. Second, outreach activities can be designed with the knowledge that participants will have varying levels of spatial ability. Extra supports/alternative paths can be provided to those with low spatial ability and/or activities can be designed to promote the development of this ability if even to a small extent. Promoting spatial ability development could be very empowering in other ways including transfer to improved performance in mathematics and other Science, Technolgoy, Engineering and Mathematics (STEM) subjects that are foundational to engineering. Those who provide engineering outreach activities should be aware of how spatially demanding their activities are and make sure all children, including those with low spatial ability children can engage successfully and even develop their spatial ability to some extent.

2 WORKSHOP

2.1 Workshop Design

In this workshop, we present a range of hands-on activities that can be used to both promote engineering education and careers to young people and expose them to spatially challenging activities, thereby achieving more through an outreach activity. The target age group for the workshop is 8- to 12-year-olds but a wider range of age groups was discussed during the workshop.

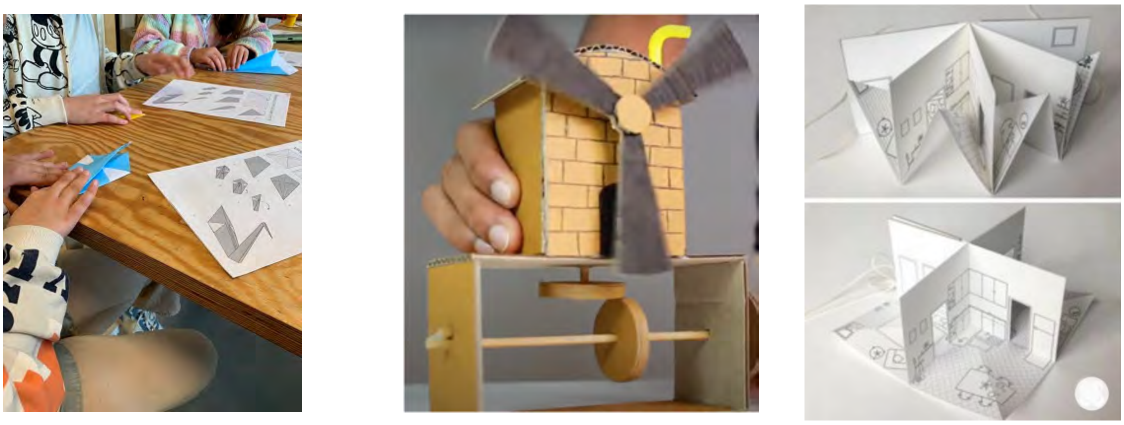
The workshop began with a short outline of why spatial ability is so important to achievement in engineering education with reference to several research studies on the topic. Attendees were then asked to form groups and engage with one of three different outreach activities that have been designed to expose children to engineering and to challenge them to exercise their spatial ability. These activities involve design thinking, problem-solving, 2D and 3D visualization and making and have been informed by an extensive review of the literature on this topic.

2.2 Significance for engineering education and attractiveness of the workshop topic

The workshop seeks to build on previous work that has been done on engineering outreach by adding spatial ability as a new element in designing and delivering outreach activities. In addition to thinking of outreach activities as fun, challenging and rewarding, we seek to include spatial ability as a key component so instructors ensure children with low spatial ability have a positive experience and even try to use the activities to promote development of this key ability.

2.3 Target audience, participant knowledge required, target numbers of participants and restrictions on size if appropriate.

Aimed at anyone who is or may be in a position to run or participate in an engineering outreach activity, the workshop requires little prior knowledge other than an understanding of what outreach is and that hands-on activities are a way to promote engineering to children. Given the limited time for the workshop, examples of completed artefacts were demonstrated rather than asking participants to make the artefacts themselves. No upper limit on numbers of attendees was imposed.



(a) Origami (b) Carboard Automata (c) Folded House

Figure 1. Examples of outreach activities that have a spatial ability focus.

2.4 Enhancement of knowledge and dialogue on the workshop topic

Spatial ability has been shown to consist of different factors, rather than being a single construct (e.g., Schneider and McGrew 2012). Mental rotation, spatial visualization and spatial orientation are factors that can be tested and developed through hands-on activities. Shown in Figure 1 (a), Origami requires paper folding and spatial visualization to see 3D shapes emerge from 2D patterns; it brings in a design theme or challenge. Cardboard Automata, shown in Figure 1 (b), has rotating wheels, cams and pulleys that require mental rotation and mechanical reasoning, both aspects of spatial ability. As a topic it can be easily connected to engineering. The Folded House, shown in Figure 1 (c), challenges participants to think in advance how a 2D pattern will become a 3D object; it has an architectural theme but can be adapted to other themes or contexts.

These different possibilities – Origami, Cardboard Automata and Folded House - were presented to those who attended the workshop. All were asked to join one of three groups, based on their personal preference for an activity. Within groups, members collaborated with each other to brainstorm a lesson plan for the activity. Each group then critically evaluated their lesson plans with regard to:

1. Creativity
    a. What is the potential for creativity development?
    b. At the start of the activity, should children be provided with finished artefacts or not?
    c. What is required to ensure creativity is not avoided?
    d. How can creativity be included in this activity?
2. Age
    a. What age group could you use this with?
3. STEM
    a. To what extent to which it will promote STEM.
    b. How do you see these promoting STEM or how can the STEM connection be emphasized?

Each group was then asked to report back on this evaluation.

3 RESULTS

3.1 Origami

Two lecturers from TU Dublin's civil engineering department participated in the origami part of the workshop. Most of the time was spent on a discussion on how the workshop could be adapted to their own teaching practice. Although the original origami activity was designed for children of late primary school-age, the participants noted a resemblance between the origami activity and the activities used in introductory courses for first-year university students. For example, the activity could be adapted for structural engineering courses to replace the well-known ‘spaghetti bridge’ activity, by having the students use modular origami parts instead of spaghetti. Adapting it to resemble subject-related material more closely could help to answer the ‘why?’ question that many students need as motivation, when the motivation that their spatial thinking skills will benefit from such an activity could be too abstract. This was the main concern that the participants had with the origami workshop: how can it be made explicit that this relates to STEM? Another approach the participants suggested was to adapt the activity to focus more on reverse engineering existing models in a group, which could also aid the students to learn how to collaborate. In conclusion, the participants found that with some adaptations, the origami activity could be an interesting way to introduce fresh first year students to fundamental spatial aspects of STEM practice, such as reading diagrams and visualising multiple transformations to an object, help them to think about creative problem-solving as a structured process they can learn, and finally be a good way to help the fresh students to make friends and practice collaboration.

3.2 Cardboard Automata

Six educators from universities across Europe and the UK participated in the Cardboard Automata workshop activity. The participants were asked to critically evaluate the activity with regards to prescribed criteria: creativity development, suitable age, and the promotion of STEM.

Initially the group actively explored the working examples of automata and reviewed a sample lesson plan and a detailed instruction booklet that were provided. The automata examples provided were developed by a range of age cohorts from ages 8 to 10 and 17 to 80 years in primary and tertiary levels. The participants feedback initially focused on the adaptability of the activity making it suitable for all ages even as young as 4 years old with the flexibility of increasing and decreasing its complexity to suit multiple learning styles and abilities. The participants discussed the flexibility of the activity agreeing the ‘narrative’ or creative aspect of the automata made space for educators to focus and adapt the activity to different scenarios and learning outcomes. Debate surrounded the provision of working examples both in terms of impacting creativity and motivation however it was agreed that examples of the working mechanisms and cam wheels was essential especially for younger cohorts. Participants also discussed the benefit of an instructional video played on a loop for younger children to enable independent engagement and problem-solving.

One of the main concerns centred around which aspect of the activity would capture children’s interest the most: the creative narrative above or the mechanical reasoning below (a central feature of the research project). It was noted that the children could spend most of the activity developing their favourite part and questions were raised as to how to emphasise the mechanical reasoning as the main learning goal. Would creative learners focus only on the narrative and vice versa? This became a key consideration with participants agreeing that the role of the teacher was key in providing clear instruction and managing the staged approach to the activity.

In conclusion, the participants found the automata to be an actively enjoyable ‘hands on’ project for engaging learners of all ages in STEM activities. With additional education supports in terms of ‘how to’ videos and explicit mechanism instructions especially for younger children participants agreed the activity would be suitable to all ages and could easily integrate into primary, secondary, and tertiary classroom environments and curricula. Participants also found the flexibility of the activity important enabling educators to relate learning to real-life mechanical systems, the potential to introduce technology, and emphasised the importance of creative problem-solving aspect of the activity.

3.3 Folded House

Five educators from institutions across Europe, the UK and the USA participated in the Folded House workshop activity. These participants were also asked to critically evaluate the activity with regards to prescribed criteria: creativity development, suitable age, and the promotion of STEM.

The group were provided with finished working examples of the activity, cutouts for active engagement and a set of printed instructions. The main discussion point centred on how easily the activity could be adapted to suit all disciplines within their own teaching practices (for example: build a lab and learn lab equipment in the context of chemistry education, design an exhibition space instead of a house in the context of general design). Participants found the activity could be made either very simple or more complex to suit learning outcomes or topics across multiple fields.

The folded house activity was designed to engage learners in 2D to 3D transformations and the participants agreed the learners would need the instructional sheet provided and working examples to engage successfully with the activity though 'hands on, minds on' theories of design learning.

Like the Origami Workshop, the participants suggested a reverse engineered approach to the folded house activity. Introducing technology, it was suggested that second and third level students could use CAD to work out the starting point or net of the house through hands on interaction with a finished house example.

In conclusion, the participants found that the activity could be developed to suit a broad age range from primary through to tertiary levels with increased complexities to suit older age cohorts. It was agreed the activity was flexible and could easily be adapted into their own teaching practices. The participants noted the relevance of the activity with particular focus on developing spatial cognition important to STEM disciplines including architecture, engineering, and chemistry.

4 SUMMARY

All three activities were considered to be suitable activities for promoting or exposing children (and adult learners) to STEM. Adaptations are needed depending on the skill level, mostly determined by age, of the audience and these adaptations can be easily implemented by e.g. providing a video to guide construction or a partially completed artefact. An interesting finding from the discussions was the potential for these activities to be integrated into existing STEM higher education courses such as using origami to demonstrate structural concepts to engineers or the folded house to create a pre-lab learning activity for chemistry students. The activities will now be adapted based on this feedback and delivered to children as part of the next phase of this research work.

5 ACKNOWLEDGMENTS

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ENGINEERING EDUCATION RESEARCH: REVIEWING JOURNAL MANUSCRIPTS FAIRLY, CONSTRUCTIVELY, EFFECTIVELY

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Conference Key Areas: *Fostering Engineering Education Research*
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ABSTRACT

Peer review is the mechanism for quality control in academic journals. When a manuscript is submitted to a journal, the editors invite other researchers – peers – to review it anonymously. The reviews should serve to support the journal editors in making decisions, and to support the authors in improving the manuscripts before publication. Therefore, reviews need to be fair and constructive. As reviewing can

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also take considerable effort, it is useful for the reviewer to consider how to do it effectively. Given the important role of peer review in a field, and the considerable effort it takes, it is valuable to jointly consider all these aspects of reviewing in a dialogue with reviewers, authors and editors. This paper presents the outcomes of such a dialogue with 49 participants in the field of engineering education research.

1 BACKGROUND: FAIR, CONSTRUCTIVE, AND EFFECTIVE REVIEWING

1.1 Peer review as a way to safeguard and enhance quality

Academic journals publish papers after a process of peer review. When a manuscript is submitted to a journal, editors will initially screen it and decide whether it should proceed for peer review. The editors then invite other researchers to read the manuscript and anonymously provide a review. The main components of a review is a *recommendation* to the editor with regards to their decision about the manuscript, and a set of *comments* to the author. In these comments, the reviewer can justify the recommendation and suggest how the manuscript can be improved.

The function of the peer review process is first to support the journal editors in making *fair* decisions by helping them identify which manuscripts deserve to be published. The task is further to *constructively* support the authors in improving their manuscript before publication. The peer review process often goes through some iteration to help authors improve their research ideas and processes, as well as how they communicate these ideas and methodologies to the readers. It is through this process of selection and enhancement that the quality of publications is safeguarded. By extension, this is how the whole research field can establish and maintain respect. Reviewers play a vital role – without peer review there can be no respected field.

1.2 The work of reviewing

Reviewing manuscripts is a rewarding task since there is much to be learned from engaging in the work of others. It can be particularly helpful to experience the editorial process from the inside, making it easier to take one’s own manuscript from submission to successful publication. As reviewing can also be time consuming, it is a wise investment to improve one’s skills to do it *effectively*.

1.3 The need for discussion

For all these reasons, it is beneficial for a research field to have an active discussion about peer reviewing among reviewers, authors, and editors. Participating in this dialogue is rewarding particularly for those taking on new roles, be they reviewers who are making their first experiences in reviewing manuscripts or doctoral students who are relatively new as authors.

2 ABOUT THE ACTIVITY

2.1 Aims

At the SEFI 2023 Annual Conference in Dublin, the authors organised a workshop focused on peer review of journal manuscripts in the field of engineering education research. Both new and experienced reviewers were invited, with a particularly warm welcome to doctoral students in engineering education research.

The workshop was facilitated by a team of editors of three leading engineering education journals:

- *European Journal of Engineering Education (published by SEFI)*
- *Journal of Engineering Education (published by ASEE)*
- *IEEE Transactions on Education (published by IEEE)*

The workshop aimed to guide the participants through the following aspects:

- Introduction to the three journals' aims and scope
- Discussing the general review criteria and review processes used in engineering education research journals, and how to apply them
- Taking into consideration particular aspects of a manuscript that a reviewer should consider
- Providing constructive suggestions to authors in improving their manuscripts and to editors in making their decisions on how to reply to authors
- Time management, enabled with effective strategies for producing articulate reviews

2.2 Workshop structure

The total duration of the workshop was 60 minutes. The total number of participants, including the facilitators, was 49. After brief introductions of the three journals, participants were asked to divide themselves into groups of about 4, with one editor (facilitator) in each group. Through discussion, the groups each made a virtual poster, entitled "*Advice for reviewers*". The results were then discussed in plenary. At the end of the workshop, participants were invited to sign up for volunteering as reviewers for the journals.

3 FINDINGS

3.1 Advice for Reviewers

Below the posters are copied as created by the groups.

Poster 1

- Be aware that you're giving feedback to a human being who will feel a certain way about it; humans make mistakes; be nice
- Give actionable feedback, specific suggestions to help improve the work
- Describe what you read in the paper → in case two reviewers don't agree, this is more convincing and informative feedback for the editor
- You can add briefly where your point of view comes from if you think it is relevant (i.e. seeing something through a different theoretical lens)
- Even if you think it is a paper of poor quality, try to give as much detailed feedback as possible to help the writer understand and to help them improve
- A template or review guide would be useful

Poster 2

- Read the abstract carefully to ensure your expertise matches that of the manuscript.
- Ensure that you have time to read the entire paper to do it justice.
- Be careful about predatory journals. Good advice is to review for journals you've read or published in.

- Evaluate what is given - suggesting completely different methods, etc. is not useful or constructive
- A high quality one-page review is better than a high-quality 20-page review. Be concise! Don't do copy editing!
- It's good to provide a quick summary of what the article was about (to show your interpretation), but this should not be the focus.
- Include strengths and areas for improvement.
- It's okay to suggest the writing to use polishing, but it's not okay to suggest a native english speaker should edit the manuscript.
- Suggestions for how to review:
  - Read the whole article and take notes, then organize notes into major and minor points
  - Can also organize points into strengths/areas for improvement
- When you read the reviews of other reviewers, learn from them! Compare your perceptions to theirs
- Phrase your comments carefully - be constructive!
- Use the "notes to the editor" box. Some editors like when you include a two-sentence summary of your thoughts.
- Use the available APA guides for use of inclusive language.
- Common reasons an article might be rejected:
  - Misalignment across sections
  - Not enough time on the discussion/conclusions
  - Not returning to the literature in the discussion section
  - Inappropriate use of methods

Poster 3

- Make sure to actually read the paper
- Make sure that you having engaged with the paper becomes clear from your review
- Check title, abstract, reference list (unspoken rule: reference other papers in the journal, editors, and so on)
- Be aware of bubbles, diversity of meaningsl
- No grammar, basic structure needed - you don't need to copy-edit or proof read the paper
- Notation can matter (is it interesting to the readership, is that relevant for understanding)
- Stay within your lane ☝️ Focus on what you know about (and hedge what you do not). Reflect on your expertise.
- Make sure the correct source is used (not only the most recent), but also keep in mind that there might be recent publications.
- Formulate the review constructively and friendly.
- Provider examples or rationales for suggested improvements
- Do not suggest to cite the work of yourself
- If in doubt, you should check sources

Poster 4

- Important to be objective, enough details to the authors to review the manuscript
- Be constructive

- Give specific advice on what improvements are needed, and in which sections of the paper
- Pay attention to the methodology of the paper (including how the results are being evaluated) and offer suggestions on alternatives
- Make sure you understand the journal scope and aims and how manuscripts are assessed: for example for EJEE its usefulness and scholarliness
- Be kind
- Especially be sensitive to interdisciplinary research/academics
- Use the same principles that we use in giving student feedback (e.g specific, useful, cover both quality of arguments and presentation)
- Don’t miss the minor changes that are required (e.g references, captions, typos etc)
- Reviewers are not proof readers, but do all journals have a proofreading / copyediting stage of the process
- Make suggestions as to other literature sources
- Don't let poor English be a reason to reject, rather encourage authors to get it proof read/ reviewed by native speakers

Poster 5

- Follow the guidelines
- Dont care about details
- Read through the paper and se if you understand the message. Then check for relevance (up to date/of interest) and coherence by means that aim and rqs are answered.

Poster 6

- Be nice in your use of language even if you think the paper is not good. People worked hard on writing it
- Make sure your criteria are objective and also explain why you reject based on these objectives so they can learn.
- Try and be as specific as you can be. Dont say that section is unclear, please fix. Do say, I find the section on X hard to follow. Can you provide a more detailed description for instance or explain your motivation of choosing the method.
- Write the type of review that you would want to receive even if it is negative.
- You do not have to agree to review every paper that is assigned to you
- Your opinion to accept / reject a manuscript is advice to the editors. They decide whether to accept or reject and need sufficient information.
- Give feedback on two levels: higher order, high priority and on detailed level on inconsistencies in wording
- Review in two stages. First make rough notes and then write detailed constructive feedback
- Suggest an alternative outlet for paper that is good but out-of-scope

Poster 7

- Be kind and constructive
- Be as precise as possible
- Don't be afraid of saying you don't understand something
- Focus on content and if it is scholarly rather than correcting language

- Keep a readers perspective

Poster 8

- Timely information can be provided upon initial evaluation.

Poster 9

- Make sure that you have enough expertise in the area.
- Think about including positionality statements as the reviewer.
- Sharing your review process with early career colleagues.
- Good idea to publish reviews next to the paper
- Giving constructive feedback that is highly detailed/specific.
- You are a reviewer not an author, it is not your duty to rewrite papers.
- Try to see the value that the paper brings to the community.
- Start with positive feedback and outline the potential impact.
- Construct a review template over time.

Poster 10

- Look at the other reviews that get sent to the author - see different styles.
- Your review style will depend on the quality of the manuscript - you can be pragmatic with your approach - think "what will help the author the most?"
- You can put links and resources in your reviews if these could be helpful for the author(s).
- A reviewer is like a detective - checking references etc. be rigorous.
- To help your time management - go through the whole paper first and make an initial judgment (if reject then you don't need to go through line by line, identify grammar errors etc. just give key points that would improve the manuscript most).
- If many grammar errors then you can highlight on first page and then if there are a lot, you don't have to continue - you can just point to a proofread (but do this sensitively).
- Remember that you are making suggestions only - authors do not need to make the changes but should be responding to your feedback with a rationale (you can
- Respond to accept/decline email and communicate with Associate Editor if you would like an extension (if you don't indicate accept/decline, you may be removed from the reviewer list)
- Split feedback into major concerns and minor concerns to help the author see where to focus their revisions.
- Can ask Associate Editor for support in reviewing - you can sometimes get asked to look at a specific element of a manuscript rather than the whole (adding your expertise to the reviewer profile can be really useful here to help you get relevant manuscripts).
- Create own workflow framework for reviewing to help time management
- Do
  - Check some references
  - Use constructive and neutral language
  - Be open minded
- Don't
  - Correct all grammar/typos (you don't need to do this)

    - Make assumptions about the author
- Frustrations of reviewers!
    - When revised manuscripts come back virtually unchanged, without rationale for not changing in response to reviewer comments.
    - Being removed as a reviewer after accepting, as may be working on manuscript at time and feel
- Useful resource to find journals to review for:
    - https://reen.co/eer-journals/
    - Visit https://beallslist.net/ and check both the journal and its publisher from the list of potentially predatory publishers there, even though it is not the only way to check journals, it is certainly a good place to start.

Poster 11

- Rubric or Checklist of assessment criteria.
- Time management for reviewing
- The comments is more important than the ranking in different review indicators
- Make sure you fully understand the paper (e.g. context, purpose, methods)
- The contributions need to be linked to the results, research scopes and results. Claims well supported by evidence
- Start giving positive feedback as the encouragement and help authors to keep
- To be fair and objective. Don't make the author's work about your own work. That is honor author's decisions and research.

4 FINAL REFLECTIONS

Some themes are recurring through many of the posters. In the following, we reflect on advice related to fairness, constructiveness and effectiveness.

4.1 Reviewing Fairly

Several posters contain comments regarding *fairness*. One recommendation is to only accept review assignments within one's area of expertise so that reviewers fully understand the manuscript. It can also help to make one's position clear in a positionality statement, and clearly indicate any parts where one has less expertise. Some advice relates to the quality control function, for instance checking references "like a detective". Reviewers are also recommended to communicate with the editors, for instance by clarifying the recommendation in a short confidential comment. It may indicate that the groups have experiences of poor reviews when they emphasise such basic ideas as making time for the review and reading the paper.

4.2 Reviewing Constructively

The posters were dominated by the themes related to *constructiveness* of reviews. Kindness features in most posters. It implies recognising that there is a human on the receiving end of one's comments, and therefore the recommendation is to be encouraging and use friendly, neutral language. One idea is to split the comments into major and minor issues. Being constructive also means being helpful to the authors in making improvements. Making feedback actionable is for instance being specific on what needs to change, in what parts of the manuscript, and how this can be done. Suggesting references to missing or highly relevant literature is appreciated, but not promoting one's own. It is recommended to focus on the manuscript as it is, rather than suggesting new work or new methods.

4.3 Reviewing Effectively

With regard to *effectiveness* of reviewing, some groups mention time management. First it is important to choose carefully which journals to review for. The recommendation is to review mainly for the journals that we read and publish in, and carefully check up lesser known ones to avoid predatory journals. One piece of advice is to read the paper first for an initial judgment, and in case of recommending rejection focusing on major feedback only. The advice in the posters is divided with regards to whether reviewers should support authors in minor editing. Some ways to improve one's reviewing is to carefully read also the other reviews when the journal copies the reviewers on all feedback that was sent to authors. Experienced reviewers are also recommended to engage junior researchers in reviewing, starting under guidance.

5 ACKNOWLEDGMENTS

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FUTURE PERSPECTIVES OF CAPACITY BUILDING IN ENGINEERING EDUCATION

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Keywords*: Capacity Building, Educational Development, Pedagogical Development, Engineering Education careers, Pedagogical skills and knowledge*

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1 MOTIVATION

This workshop aimed to encourage sharing of Capacity Building practices in Engineering Education across the SEFI community and open dialogue to shape how SEFI can support the community and their practices through the Capacity Building Special Interest Group. Participants also had the opportunity to discuss their own experiences of Capacity Building, also known as pedagogical training or professional development, and compared and contrasted this to others' experiences. They considered where Capacity Building has been beneficial for themselves and their colleagues. Participants were also asked to consider areas that will require Capacity Building in the future, feeding into ideas for pan-European support that SEFI might provide, including consideration of the environmental facilitators and barriers for Capacity Building.

The aim was for participants to develop an understanding of the wide variety of ways in which Capacity Building can be organised in Higher Education institutions across Europe, which might provide inspiration for improving current practices within their own institutions. It was also intended for the workshop to support the building of a Community of Practice of educators who are involved with and/or lead Capacity Building activities in their own institutions or within the broader SEFI network.

2 BACKGROUND AND RATIONALE

Capacity Building is also known as ***pedagogical training or professional development in education*.**

Engineering educators understand that the world is changing quickly and the engineers of the future need to ethically balance technology, sustainability and the demands of growing populations in a world where large-scale projects are becoming the new normal, communication is often instant and cultures are mixing more widely. Engineers require new competencies, especially with the growing importance of engaging with the Sustainable Development Goals (SDGs) (Diaz Lantada 2020, 1814, Beagon et. al 2023,1). These include dealing with conflicting values; decision-making using incomplete complex data; transdisciplinary collaboration; and increasing competition for resources.

But how do we make sure that we, as educators, build our capacity to support the development of future engineers? How do we ensure engineering educators at all stages of their career have the appropriate pedagogical skills and knowledge to shape education sustainably and successfully?

Capacity Building is considered important for engineering educators (Chen et al. 2021, 900), but activities are governed and delivered in many different ways (Kövesi et al. 2022, 379). Moreover, an individual's access to Capacity Building may be limited by pre-existing structural factors, job role, the time available for personal development, and employers' recognition of its importance (Perez Foguet and Lazzarini, 2019, 772). Finally, educators who have participated in pedagogical development often face structural challenges that may hinder them implementing new pedagogical approaches in their practice - which can lead to reduced motivation to engage in further development opportunities.

(Chen et al. 2021) and (Hebles et al. 2021) indicate that Capacity Building is most successful when participants have opportunities to reflect, interact, rehearse and try out pedagogical practices. This workshop asked participants to share their experiences related to these opportunities, discussing how we can build a SEFI community of practice that supports the Capacity Building needs of engineering educators and educational institutions. We examined differences in local practices, exploring whether and how a pan-European approach could add value, shaping future direction of European Engineering Education Capacity Building, and providing inspiration for participants to take back to their own institutions.

3 WORKSHOP DESIGN

The workshop began with introductions and a short questionnaire to find out more about the participants' backgrounds. Of the 20 participants who responded, 2 were early career researchers, 2 new academics, 1 in an administrative or strategy role, 11 were experienced academics, and 4 did not fit into any of these categories.

A second question enquired about disciplinary identification ,and they could select more than one answer: 10 considered themselves to be engineering education researchers, 5 'engineering' discipline-specific researchers, 16 educators or practitioners, and 7 have industrial experience.

An overview of Capacity Building practices was then provided (Kövesi et al. 2022), and participants spent a few minutes reflecting on Capacity Building activities that they have experienced. They then moved into small groups pf between 4 and 6 people to discuss and identify aspects of Capacity Building that they consider to have worked well, those that have had little effect, and where they see future challenges and opportunities in Capacity Building. The workshop concluded with short summaries of the group discussions which were collected on a white board and in Mentimeter.

4 RESULTS OF THE WORKSHOP

The small discussion groups shared what they have observed worked well for Capacity Building and when it had added value. They generally observed that Capacity Building activities tend to focus on early career staff, with less support for more senior staff.

4.1 What works well

The groups observed that Capacity Building has worked well for them when:

- There are opportunities for hands on practice.
- There is encouragement and clear support from leadership.
- There is space to include a student role in the activities, creating a bottom up approach.

- Activities are inclusive and include a mix of sharing (dialogue) and teacher delivery (didactic) methods.
- It is ‘just in time’ and relevant to educators’ needs.

It was additionally observed that spending time in industry can be very enriching for academic staff, and that ‘food works well’(!) in terms of gaining engagement.

4.2 Barriers

A number of barriers to successful engagement with Capacity Building were highlighted:

- Staff require incentives to participate, which could include financial incentives, promotion or tenure.
- Value needs to be perceived in order for staff to participate.
- Staff need to perceive that they are learning ‘real’ skills and competences.

The analogy of carrots and sticks was used, with carrots being senior leadership actively showing value and appreciation of staff who engage in Capacity Building. This may be in the form of allocation and protection of time for staff to engage through structured opportunities for personal development.

4.3 The Future

Participants were asked to consider what Capacity Building activities they would like to see in future. This could include the skills that needed to be covered or the format that activities could take. Comments included:

- There needs to be credibility of the staff delivering – showing by example
- There could be more sharing between institutions
- Universities in the future could value teaching as much as research!
- There could be a culture change bringing increased recognition of Capacity Building activities
- Skills that it would be useful to have more Capacity Building in include:
    - Applying action research in the classroom
    - Equality, Diversity and Inclusion
    - Sustainability

o Educational Research support

4.4 Suggestions for SEFI Support

The following points were discussed regarding where SEFI could be impactful:

- The Capacity Building SIG could conduct research on the skills educators will need for the future, and the needs of educators in Higher Education.
- Creating of a European network that could support senior and experienced staff
- Help for trailblazers in institutions
- Following the Japanese Society for Engineering Education and creating a credentialed course for teaching (theirs is around PBL and actives learning)
- Creating an evidence base for the development of Capacity Building activities and of their impact.

Nevertheless, it was also raised that contextualisation to local practices will lead to the most successful and most relevant Capacity Building.

5 CONCLUSIONS

The discussions in the workshop often congregated around the common theme of the value of Capacity Building – it needs to be seen as important and relevant by both those taking part and by senior leadership, who should recognise activities through reward and by enabling participation. Social incentives were seen as key in creating an environment that is supportive of Capacity Building. This fits with many models of behaviour change where a suite of interventions around training, structural changes and incentivisation must be addressed for change to be successful.

It was noted that participants felt there were fewer opportunities for useful and meaningful engagement as they progressed in their careers, but the workshop time did not allow investigation of the specific types of support that senior individuals might find most useful.

6 SIGNIFICANCE FOR ENGINEERING EDUCATION

Connecting to SEFI2023's theme, it is increasingly apparent that we cannot educate future engineers with fluency in the SDGs without tackling competence development. Few engineering educators are comfortable teaching SDGs due to few being experts; there are tensions that occur when educating students for an unknown future requiring different types of knowledge and competencies than those traditionally taught in engineering (Beagon et al 2023, 1). High quality sustainability education requires new approaches such as active learning, project-based learning, and stakeholder collaboration, creating an urgency to build educators' capacity to deliver in these ways. There is a need for pedagogical support to build confidence in numerous emerging, and often fast growing, areas such as AI, sustainability, transdisciplinary education, open and online education and stakeholder collaboration.

Nevertheless, although growing, there remains a scarcity of literature on this important topic and opportunities for discussion with peers are limited. As a result, opportunities for interactions among individuals interested in the field are essential to build a community of practice centred around sharing experiences and learning (Wenger, 2000).

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Building Collaboration and Learning Mechanisms for Sustainable Development – a workshop

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Conference Key Areas: *Embedding Sustainability and Ethics in the Curriculum, Engineering Skills and Competences, Lifelong Learning for a more sustainable world*
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1 BACKGROUND AND MOTIVATION

The United Nations (UN)'s Sustainable Development Goals (SDG) goals provide a framework for action to achieve sustainability targets for 2030 [1]. Engineering plays an important role in the achievement of the goals through the development of innovative, sustainable solutions [2]. Said that, engineering education must prepare and educate its graduates accordingly, with knowledge and competences to act locally and positively impact globally [3]. Engineering education for sustainable development (EESD) calls for transformative, problem-oriented, contextual, collaborative (inter-and transdisciplinary), student-centred learning environments, where students and academic staff develop a deeper understanding of SDGs in relation to their own field, solve complex and ill-defined sustainability problems, possess anticipatory and systems thinking skills, and collaborate across different disciplines, institutions, and wider communities to engage in knowledge co-creation, change and transformation in order to contribute for a sustainable, fair, and peaceful future [4][5]. In sum, learning and acting for sustainability requires inter- and transdisciplinarity competence [6]. As many sustainability issues could not be resolved alone, they should be addressed in a more optimal and transformative way, namely practices, and worldviews [6]. In this sense, engineering education institutions, through their students, staff stakeholders and wider community, are required to engage in co-creative processes in order to address complex problems and provide sustainable solutions, using multiple sources of knowledge in order to challenge and transform current practices and facilitate the transition to a more sustainable future [3]. Said that, it is required that they are able to work with and across institutions, cultures and disciplines, i.e. have the competence needed to work transdisciplinarity. To do so, students need to be able to not only recognize what socio-cultural and socio-ecological charactrises them as well as the differences between them and other groups of people and their practices that impede learning and actions in relation to each other [7,8]. A good example is provided by Wanger [9] of his social theory of learning through informal community of practice (CoP). A CoP is defined as a group of people, who share an identity through a common interest in a subject, and collaborate through a period of time to share ideas, determine strategies, develop solutions, and achieve shared goals and views. CoP are learning communities composed by practitioners, who share a common "language". Collaboration across such communities requires extra and explicit support, as well as the development of competences [6]. Competence for inter- and transdisciplinary work is defined as the ability to work and communicate across different practices and become agents for transformation [10].

2 SIGNIFICANCE FOR ENGINEERING EDUCATION

The workshop is based on Guliker and Oonk's [6] learning mechanism for transdisciplinary learning: (1) Identification, (2) Coordination, (3) Reflection, and (4) Transformation [6]. These learning mechanisms are identified to serve as a leverage for learning and working across disciplines and co-create knowledge and practices for sustainable development. These four mechanisms include: 1) identification, obtaining insight into current different practices around the boundary; 2) coordination, collaborating with other to address the problem; 3) reflection, learning to see the problem from each other's perspectives; 4) and transformation, co-development of new knowledge or practices [6].

Based on the four learning mechanisms proposed by Gulikers and Oonk [6], the workshop proposes an approach on how to address sustainability complexity by enabling participants to relate their discipline, teaching and/ or research with sustainability as a point of departure to build collaborations across different sectors and foster transdisciplinary learning, and consequently foster development of competences for sustainability.

3 LEARNING OUTCOMES

Participants in this workshop will collaborate with each other and use SDG as objects to cross disciplinary, cultural, and institutional boundaries, with aim to formulate problems and co-create new knowledge and solutions, working toward innovation or transformation for sustainable learning and practice.

By the end of the workshop, participants are expected to to be able to:

1. Identify to which SDG their research, or teaching, practices contribute
2. Use SDG as objects to cross 'boundaries' for collaboration and interdisciplinary learning
3. Negotiate about how SDG-relevant focus area may contribute to each other
4. Reflect on one's own practice and unfold potentials for curriculum innovation and integration of SDG

4 WORKSHOP DESIGN

The workshop utilizes small lectures in combination of groups discussions, and hands-on exercises. It targets a maximum number of participants, incl. students, academic staffs, and researchers in engineering education, who intend to integrate sustainability in their own studies and practice. This workshop comprises five sections as table 1 shows.

Table 1 Workshop structure and organisation

Part	Duration	Main activities
1. Introduction	10 minutes	Lect. 1: Welcome and overview of workshop goals (10 min)
2. Identify and coordination	10 minutes	Act. 1: Identify the challenges by individually and brainstorm on SDG-related challenges (3 min) Act. 2: Write down and relate challenges with one's disciplinary field by individually, and how does the disciplinary field address

		the social challenges that are brainstormed (3 min) Lect.2: Sum up in plenum (4 min)
3. Integration and reflection	25 minutes	Act. 3: Form the group, discuss the challenges and try to narrow it down considering the indicators of SDGs and formulate the potential challenge that could be presented (10 min) Act. 4: Mind map knowledge needed for one to be able to address that SDG-related challenge (10 min) Lect. 3: Sum up in plenum (5 min)
4. Transformation	10 minutes	Act. 5: Taking the point of departure in the previous exercise, discuss how learning environments could be transformed to integrate education for sustainability using these learning mechanisms (10 min)
5. Final remarks	5 minutes	

Different resources (e.g. literature, scripts and exercise guidelines) are provided to participants during the workshop.

5 WORKSHOP RESULTS AND FOLLOW UP ACTIVITIES

During the workshop, 20 participants from different universities formed three groups. They collaborated to cross disciplines as well as to integrate sustainability in their professional practice (e.g., teaching, research, etc.). First, they identified key challenges such as integration of sustainability in the curriculum, teacher development for sustainability, diversity, and civic engagement for student learning for sustainability, energy, internet of things (IoT), etc. Second, participants linked the challenges formulated with the 17 SDGs and their own disciplines, they collaborated with others by making a mind map in their own group to visualise such relations and connections. Their inputs were also gathered and shared in connection with Sustainability SIG group.

6 CONCLUSION

This workshop uses Guliker and Oonk's [6] learning mechanism for transdisciplinary learning as the guidance and aims to provide engineering staffs and researchers to cross their disciplinary, cultural and institutional boundaries on SDGs to foster collaboration and innovation. This workshop also reflects the current need on crossing boundaries on SDGs in the context of engineering education, which promotes engineering students, educators and researchers to solve problems in a holistic manner, and develop their competences and knowledge on both sustainability and interdisciplinary learning.

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Reflection on your personal perspective through the perspective of others. A step in dealing with wicked problems.

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Conference Key Areas*: Innovative Teaching and Learning Methods, Engineering Skills*
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Abstract

Don't we all sometimes seek the perspective of someone unrelated to our work, to get unstuck, or when we seek creativity? Engineers, educators, and students put their trust into science, protocols, procedures and models. Rightfully so, from the perspective of the laws of engineering this makes sense. This also explains why when people deal with challenges, they often tackle them (consciously or unconsciously) with their preferred strategies (Hayashi 2018) (Mezirow 2000). However, these preferred strategies might offer a false sense of security because they oversimplify the complicated nature of the challenge. People might focus on a part of problem which is easy to solve rather than addressing the bigger networked problem (Kahneman 2013).

In dealing with complex problems, it is helpful for engineers to become aware of habits and open eyes to other ways of seeing and doing, as solving (today's) multidisciplinary wicked problems often require that. (Braun 2021; Braun and Kramer 2015; Kramer and Braun 2018; Seniuk Cicek et al. 2021; Veltman, Van Keulen, and Voogt 2019). Recognizing one's own perspective is the first step towards valuing other perspectives or approaches to a problem. By understanding 'our own eyes', we can connect with and value other perspectives and alternate ways of doing something.

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This workshop introduces reflection through third person perspectives, to help participants recognize the habits that are embedded in their own perspectives. Participants can later apply the method and material used in the workshop in their own educational context. It is suitable for students, researchers, and teachers.

Learning outcomes

- Participants will become aware of their perspective in a safe and interesting way.
- Participants will experience that their own perspective impacts the way they approach (work) situations, by reflecting on these situations through others' perspective.
- Participants will receive access to the material so that they can use the format of the workshop as a tool to use with their students or peers.
- In the final conference proceedings, we will include the type of insights participants found through our workshop, what they might expect the value to be for (their) students, the impressions of the participants about what worked well and how participant intent to use it in their context.

Workshop Setup

After introductions and addressing context of this workshop, participants form groups of 3-4 persons, and they receive a template with reflective questions to use throughout the workshop. Together, they select one of the given examples of day-to-day situations in engineering education practice. First, the participants individually determine how they would respond in that situation. Next, when comparing their responses in the group, the first insights in their habits might occur.

After that the 'guests' arrive in the workshop and every group chooses which two to three guests to invite. The guests are well known actual and fictional characters that people can attribute certain characteristics to. Examples might be Pippi Longstocking, Barbie, a dictator or a puberal adolescent. To empathize with the character more easily, props that represent them are present. The questions in the template create a dialogue between participants and guests. In this way, the guests can provide their unconventional, outsider perspective on the chosen situation, because Barbie or an adolescent will respond differently.

When comparing the quest's perspective to the individual response the next insight in their personal habits is obtained. Finally, when combining the perspectives of all guests, their peers and their own, insights emerge that highlight some of the underlying patterns that are relevant in work.

In the last step of the workshop, participants transfer their self-insight to their actual work context to understand the relevance.

The workshop is closed by together reflecting on the experience and discussing its value for themselves and students.

Workshop Rationale

The workshop is playful and light-weighted. Via an indirect route we uncover underlying patterns. Doing that playfully is safer than answering questions directly.

The ‘guests’ are a slightly arbitrary selection of well-known characters that people can attribute certain characteristics to. Because of the high number of characters present and the need for a maximum of three per group, there is enough choice to make this work. Participants have freedom to choose other characters if preferred. Using well-known characters is inspired by role play and serious game design. When adopting a role, players of a game adopt the characteristics of that role as well as their behavior (Renger and Hoogendoorn 2019).

The use of a third person perspective to unveil behavioral insights is inspired by drama therapy where this creates a possibility to externalize inner subjective reality (Smeijsters 2008).

The given situations that participants choose from are common situations that are relatable but not considered personal. For example: you meet a colleague at the coffee machine that you haven't seen in a long time, but you are in a rush, what do you do? Or: you feel under the weather but have a lot of deadlines coming up: what do you do? By starting with a situation that you can relate to, but that does not feel personal, participants can be themselves without the need for role playing and social safety is created. Offering a variety of situations and characters invites participants to engage while experiencing autonomy in the choices.

Workshop takeaway

Participants gain personal insights and a practical tool for application in your professional context.
Designed for engineering education professionals, the workshop offers a reflective experience using a formatted ‘conversation’ with alternative playful perspectives. The tool and materials can be used to reflect on projects, collaborations and learning by yourself or peers or can be adapted for student use, helping them recognize their own perspectives.
Overall, incorporating new perspectives is valuable in addressing complex problems, and educating engineers with these techniques can better equip them to tackle the wicked problems of society.

Participants' Insights and Experience

The Perspective workshop sparked genuine interest among attendees due to its unconventional format, resulting in a fun and thought-provoking experience. Participants literally sat down with Barbie, Hulk and many other characters from around the world and thought what would they do in a weirdly specific work-related situation. Attendees found the structure of the workshop playful yet profound, allowing them to freely explore thoughts and behavior and collectively create meaning. They contemplated the actions of each 'guest' as well as their own personal perspectives.
Throughout the entire activity, attendees were not passive recipients; they actively engaged in conversations. One participant noted that the scaffolded design of the workshop was much appreciated as it led participants to introspection in a safe and lighthearted manner. This was the intention behind the format of the dialogue between perspectives: to make it accessible to everyone, regardless of their background or expertise, to explore their thoughts and actions playfully.

Implementation
One of the most rewarding insights was participants envisioning where they could use the dialogue between perspectives in their personal contexts. Some of them speculated about its applications in various scenarios, ranging from team dynamics, where it could foster understanding and collaboration, to senior academic groups, improving departmental relationships. After the workshop, attendees received a version of the templates that can be quickly adapted to fit the needs of the groups they want to use it with. By sharing the digital template under creative common license, this intervention is available beyond SEFI2023 and provides them with a flexible tool to be used in their institution.

Significance to Engineering Education
In the realm of engineering education, giving insight on diverse and personal perspectives stands as a valuable asset not only for students but also for academic staff and management. It facilitates a process that allows individuals to gain a better understanding of their own positioning and provides an opportunity for transformative insights regarding one's practice, as well as the ability to acknowledge and value different viewpoints. This skill, relevant in social constructivism theory, is helpful for engineers in navigating the intricate web of multiple truths, enabling them to balance diverse stakeholder perspectives with finesse and understanding or collaborate in multidisciplinary teams.

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Campfire Talk game, an unsupervised intervision game for students and staff.

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Conference Key Areas*: Engineering Skills, Transversal Skills*
Keywords*: Reflection, Intervision, Ludodidactics, Serious Game*

Workshop overview

Are you witnessing students facing concerns, difficulties, and problems throughout their educational journey? Perhaps you know PhDs, lecturers, or support staff who encounter challenges in their educational, research, or teaching paths. Openly addressing these issues can prove beneficial in all of these scenarios! While coaching is a potential solution, it can be time-consuming and demanding, right? Instead, let them have a Campfire Talk: a non-intrusive and socially safe serious game that requires no supervision. It provides a platform for discussing struggles that in practice are often difficult to address or overlooked but can deeply affect individual or group behavior. During this workshop, participants will have the opportunity to experience the game firsthand, followed by an exploration of its underlying mechanisms and potential application in their own educational settings. An open-source version of this game will be available for participants.

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Learning outcomes

In this Campfire Talk workshop, participants will:

- Recognize shared struggles and challenges in their educational, research, or teaching journeys.
- Experience a coaching tool that requires minimal time or skills from supervisors.
- Understand the benefits of open discussions, the importance of creating a safe and supportive environment for discussing struggles, and the positive impact from the process.
- Gain practical experience with the Campfire talk and have insight into the use of ludodidactics in the design of the game.
- Engage in reflective discussions, analyzing the game from their perspective, but also considering its potential impact on students, PhDs, and staff in their own educational settings.

Workshop Activities

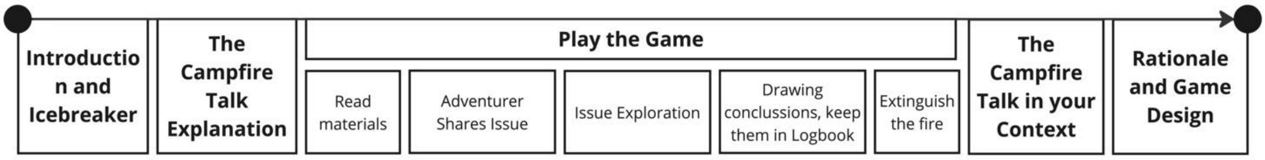
The game is suitable for researchers, educational staff, students, and in general, anyone that has experienced issues in professional or educational settings.

The session starts with introductions and an explanation of the game's background, followed by a round to play the game. The facilitator will arrange the materials needed, and explain the roles and steps involved.

Participants will be divided into groups of 4-7 individuals. Each player assigned a specific role (Adventurer, Explorer, Fire Master or Logbooker). The Adventurer shares an issue from their education or research that they feel comfortable discussing. The Explorers ask open-ended questions to gain a comprehensive understanding of the issue. The Fire Master moderates the conversation, and the Logbooker records insights derived from the discussion, which will be shared with the Adventurer.

(Figure: visual of the Campfire talk game)

By utilizing own issues, participants experience the game's impactful coaching qualities directly. Following this experience, we shift to a metacognitive reflective perspective. We examine the game from the participants' viewpoint, as well as from the perspectives of students, PhDs, or lecturers in a typical educational setting. This discussion explores contextual differences among participants. Additionally, we briefly discuss the ludodidactic design and its implementation in our institute.



Game Rationale

Burnout, anxiety, loneliness, and other mental health issues are a big problem in universities (Boston 2021). Many students in our university are struggling alone, with issues like those of their peers. They are unable to share their worries and struggles with fellow students or supervisors and have difficulty asking for help. Supervisors are often unaware of these struggles or shy to act on them.

Discussing struggles is hard and it takes courage to share and open up. These conversations need social safety, dialogical skills, empathy, awareness, vocabulary, and other factors. Engineering education is not characterized by providing students space and skills to openly discuss these things.

This inspired the creation of the Campfire Talk game, co-created with students and developed using ludodidactics, a didactical approach to developing teaching and learning behavior based on game principles (Renger and Hoogendoorn 2019). It is a serious game, which aim to create an environment where the players voluntarily want to learn and use the knowledge and skills. It creates a way of being able to do something without having to master it (Renger and Hoogendoorn 2019).

In the design phase of the Campfire Talk game, we deconstructed having a good conversation into process steps and helpful tools. Next, we reconstructed that in a way that people with no or limited conversational skills can have conversations together wherein emotions are discussed, and self and peer coaching occurs. The following six game mechanics make this work. (Hunicke, LeBlanc, and Zubek 2004; Renger and Hoogendoorn 2019)

(I) The theme of an adventure and a campfire is a powerful metaphor: since ancient history, people have had different kinds of conversations around a campfire (Dunbar 2014). It normalizes running into issues if you reframe it as an adventure.

(II) Identity: Players personalize their game by choosing what they want to talk about. Therefore, the topic is always relevant to the player.

(III) Roleplay: Players are assigned a role and adopt its corresponding attitude.

(IV) Performance support: Players are helped in their role by tools such as a guide with open questions, a logbook, and tips.

(V+VI) Helping and Knowledge Sharing: players are put in a position where they can help each other out by sharing.

The effect of the game is that it creates a socially safe space and facilitates having a good conversation between peers where both introverted (quieter) and extroverted (talkative) have space to talk. It names and normalizes issues and accompanying emotions. Participants feel relieved that they are not alone in struggling with an issue. It shows that there is a wide spectrum of reactions and solutions to similar problems, encouraging and empowering them to see new ways of dealing with their issues. Players also experience respect and sympathy for others when they understand them better, possibly benefiting empathy skills.

Take home message for participants.

Through the workshop, participants will gain firsthand experience and access to a coaching approach that requires minimal time and skills from supervisors. This coaching method empowers students, PhDs, and staff to effectively address the challenges and issues they encounter in their educational, research, or teaching journeys. Furthermore, participants will have the opportunity to access an open-source version of the Campfire Talk game, enabling them to continue utilizing this valuable tool in their own context.

Participants' Insights and Experience

This edition of The Campfire Talk was met with collective enthusiasm, evident in the meaningful conversations it sparked across the room. The game, now in its latest stage of development, led to discussions about personal struggles about various topics, including course design or supervision. As one participant expressed, "*It's really nice because I felt free to talk about my 'dirty laundry,' even with strangers.*" Participants were deeply engaged, with several groups continuing their discussions even after the official workshop time ended.

Upon reflecting on their experience, attendees highlighted the game's universal applicability. Many noted that it could assist not only in professional settings but also personally. Quotes such as "*I think it would help everyone, in any setting*" and "*Everyone should play it; it would make them a better person... Or at least better at asking questions or listening*" were collected. Some participants appreciated the specific challenges and skills associated with each role in the game, such as: asking questions, moderating discussions, and active listening. For instance, explorers were encouraged to ask open questions instead of giving advice, fostering a specific skill set that the game provided materials to practice.

Implementation

It was widely acknowledged that The Campfire Talk presents a relevant solution to a latent and apparent need across numerous universities. Attendees expressed keen interest in the game's development and how they could implement it in their institutions. The enthusiasm was palpable; three individuals volunteered to translate the game into their native languages, one offered to printing overseas for sustainable production, and others contemplated introducing it to their student, PhD, or staff groups.

Significance to Engineering Education

The Campfire Talk provides a safe space for exploring struggles freely, incorporating ludodidactic elements that facilitate this exploration in a structured and accessible manner, promoting empathy and understanding. Witnessing the impactful responses and the game's ability to touch upon the basic human need for connectedness, it becomes evident that it is a powerful tool applicable in diverse settings and groups.

For those interested, the open-source version of The Campfire Talk is available on our website: [Link to the website]

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Application-based learning of signal analysis methods with the help of a graphical open-source software

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ABSTRACT

In almost all engineering disciplines, engineers need to evaluate and extract information from time-dependent quantities, making signal processing and analysis a central topic in engineering education. The theoretical foundation is anchored in many courses, however, often only few application-based learning opportunities are offered. To provide these opportunities without the need for expensive hardware, a graphical open-source software is developed. This workshop offers a first opportunity to explore how a graphical software can be used to learn signal processing and analysis methods.

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1 MOTIVATION

Time-dependent signals occur in nearly every engineering discipline, e.g. electrical engineers measure voltage signals, mechanical engineers and civil engineers deal with mechanical oscillations and audio engineers with audio signals. As engineers need the ability to process and extract information from these signals, signal processing and analysis is a central component in engineering education. While the theoretical foundation is taught in detail in many courses like e.g. signal theory, the curricula often offer only few application-based learning opportunities. This is understandable given that the processing of physical signals requires specialised and often expensive experimental equipment. Alternatively, students can experiment with digital signal processing, but this often requires specific programming skills. This lack of application-based learning in this specific field means that the students often only have the theoretical knowledge of signal analysis and processing methods. This becomes evident when students are confronted with real-world problems. They often possess the necessary knowledge and they can explain specific methods, but do not know what to apply to a given problem.

2 A GRAPHICAL SOFTWARE TO LEARN SIGNAL ANALYSIS METHODS

To overcome the issues mentioned above, graphical software can be used to enrich teaching. For example, research performed by Balakrishnan and Woods (2013) has shown that physical experiments can be complemented by simulations. However, commercial software is often used, requiring the students to either buy licences or work at computers in the university. An example for an open source solution for the teaching of signal processing methods is presented by Barrio et al. (2023), however the focus here is on software defined radios.

To provide a more general, easy-to-use signal processing software, the ‘Multi Channel Analyser’ (MCA), is developed (Measurement Engineering Group 2023). It provides experimental learning opportunities with a focus on problem-solving to students at the undergraduate level. The MCA, which is developed as an open-source project, enables virtual signal processing by connecting processing blocks graphically, thus requiring no programming skills. Available inputs to the processing blocks range from virtual signal generators, audio files and input from the computer’s microphone to oscilloscopes. The output signals of the processing blocks can be displayed as plots, but also written to audio files or played via the computer’s speaker or headphones. Examples for processing block functions are low-pass filters, convolution, multipliers, and the fast Fourier transform. Alongside the numerical values of the signal, the appropriate physical unit of the signal is also stored and processed. Thus, if for example a voltage with unit V is multiplied with a current with unit A, the result is a power with unit W. It is possible to save and to load the current state of blocks, thus allowing for teachers to prepare tasks the students have to complete and for students to submit their solutions.

The MCA can be used in different courses that include signal analysis and processing, such as courses about measurement, instrumentation, and signal analysis, or in laboratory courses. For example, the function of circuits to be designed in a laboratory course can be examined virtually on a block-level to aid in choosing a fitting circuit implementation. Application in adjacent fields is also possible e.g. to demonstrate the effects of a low-pass filter—be it applied to electrical, mechanical or audio signals. As the software does not require specific hardware or expensive licences required by commercially available software, students can use it at home to deepen understanding or in a remote teaching scenario. The MCA is written in Python and also provides an easy-to-use, well-documented API to implement new signal processing blocks and may thus be expanded further by the engineering education community.

3 WORKSHOP DESIGN

In this workshop, the attendees work with the MCA and evaluate and discuss usage of such software. Attendees are asked to bring their own laptop and, if available, headphones, to be able to test the MCA in their preferred operating system (Windows, Linux or macOS). Besides basic understanding of signal analysis methods, no prior knowledge is required. At first, a short introduction is given and the attendees are prompted to install the software. An example on how an application-oriented task can be designed using the MCA will be presented. Afterwards, the attendees take the role of the student and try to solve an exemplary task themselves while the authors will assist and answer questions that arise. A subsequent discussion of the experiences in the practical part will include the following matters:

- Do the attendees already use any similar software/methods in their daily teaching? If not, could they imagine using such a software? Why/Why not?
- How was the user experience in solving the given task and were there problems in using the MCA?
- Is it considered useful to have a physical unit carried along with each signal?
- Are there suggestions for improvement?

The authors will also elaborate on first experiences in teaching with the MCA. However, as the software development is still ongoing, broad usage in lectures still has to be established and the influence on the students' learning outcome has to be examined. In the future, it should also be investigated to what extent an automated evaluation of the user interaction with the MCA is possible.

4 RESULTS

By participating in the workshop, the attendees got to know a new tool for application-oriented teaching of methods of signal processing and analysis. They had the opportunity to evaluate if the proposed software can be used in their own courses and had a first impression of the advantages and possible disadvantages.

The attendees were able to solve the given tasks without any issues. The user experience was generally graded positive, which due to the very short introduction given in the workshop confirms the easiness of use. Most attendees considered it useful to have a physical unit carried along with the signals. The discussion revealed that most teachers already use some kind of graphical software for teaching. A software which was brought up is LTSpice, which is an electronic circuit simulator. It allows to graphically build electronic circuits at a component level and to analyse them afterwards. However, it was mentioned that having to build a working circuit first poses a challenge for some students. Also, the software is limited to electrical signals and not applicable to signal processing in general. Another software mentioned in the discussion is LabVIEW, but it requires licences. Concerning licences, it became apparent that some universities provide every student with a licence from the beginning of their study program, so licensing is not seen as an issue for teachers at those universities. A software previously unknown to the authors is called DADiSP, which allows for easy signal processing and plotting of data. Like the MCA, it carries along the physical unit with each signal. The software has several plot windows and allows assigning data and processing functions to those plots via graphical menus. However, compared to the MCA, the signal processing methods are not available as blocks, but connections have to be created in dropdown menus. Thus, the signal processing chain is not directly visible.

It was seen as an advantage that the MCA is an open-source software, as students interested in learning how to programme digital signal processing functions can look up the implementation. As the workshop was conducted by the developers of the software, the attendees also had questions about some features. It was asked if real-time processing and a direct connection to MATLAB is possible. This is currently not possible, but signals can be exported from MATLAB as files and then get imported in the MCA. Another question was, if the transfer function of processing blocks can be displayed. This is deliberately not implemented, as there is a signal generator block creating an impulse, such that students can visualize the impulse response themselves.

5 CONCLUSION

The discussion showed that using graphical software is considered a useful tool for teaching and learning signal analysis methods. With the MCA we presented a software which can be used in such contexts. The MCA was considered appropriate for this task by the attendees. The authors are still looking forward to getting in contact with people who are willing to participate in the future development of an open-source software that is driven by the engineering education community.

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PRACTICAL TOOLKIT FOR EMBEDDING ETHICS IN THE ENGINEERING CURRICULUM

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ABSTRACT

The need to embed ethics into the engineering curriculum is a collective imperative if we are to successfully navigate complexity, uncertainty and challenging ethical issues to build a sustainable society that works for everyone. To maximise positive impact, behaviours such as inclusivity and sustainability must become instinctive – golden threads running through everything that engineers think and do. Proactively, bringing engineering ethics to the fore in engineering programmes is one way UK

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higher education equips future engineers with the skills and mindset they need to succeed.

This workshop brings together best practice from expert practitioners across the UK, introducing a nationally curated ‘Engineering Ethics Toolkit’. To help educators to know and use the toolkit the workshop offered an attractive translation of engineering ethics teaching theory to the practice of engineering education.

In this workshop, participants were introduced to a pragmatic approach to integrating ethics content into their teaching, using examples and a detailed and interactive curriculum map, which connects the elements of the toolkit.

Our aim is to ensure the toolkit becomes an ongoing, regular component of engineering teaching and highlighting excellence in integrating ethics. The workshop was as a seed to encourage further case studies to be developed and to also explore what can yet be done in this space to ensure the next generation of engineers are well-equipped to address the ethical issues they face.

1. Motivation

The need to embed ethics into the engineering curriculum is a collective imperative if we are to successfully navigate complexity, uncertainty, and challenging ethical issues to build a sustainable society that works for everyone. Proactively, bringing engineering ethics to the fore in engineering programmes is one way UK higher education equips future engineers with the skills and mindset they need to succeed. However, engineering educators without an expertise in ethics may lack confidence in integrating this content into their technical modules. The purpose of the session was to demonstrate how an internationally curated 'Engineering Ethics Toolkit' can enable educators to embed ethical context within their modules and programmes.

2. Background and rationale

In the wake of high-profile events like COP-26 and disasters such as Grenfell, scholars, industry groups and advocacy organisations have increased their calls to make ethics a more visible, relevant, and essential component of engineering education and practice. For instance, a forthcoming handbook from SEFI on Engineering Ethics Education (to be published in 2024) and the recently published International Handbook on Engineering Education Research (Routledge, 2023) highlight new developments in research and pedagogy in this area, while recent updates to accreditation standards have explicitly called for students to gain knowledge and experience with ethical issues related to engineering (Engineering Council, 2020). Most notably in the UK, the Royal Academy of Engineering's Ethics Reference Group (2022) published a report calling for an improvement in the profession's engagement with all aspects of ethics.

In response to this call to action, an Engineering Ethics Toolkit has been produced by academics and engineering professionals from around the world. The Toolkit is intended to meet the need for a better understanding of the concept of ethics and support for issues surrounding its teaching, and to demonstrate where and how in the engineering curriculum ethics teaching can be embedded and provide teaching resources to support with this.

3. Workshop design

This session used Socratic-style discussion, small and large group activities, and reflective learning approaches.

1. First, participants reported on their existing experience with ethics education and suggested a list of current ethical issues in engineering.
2. Next, workshop facilitators introduced and described resources found in the Engineering Ethics Toolkit that relate to the identified issues. We accessed the Toolkit's Ethics Explorer, demonstrating how users can find resources pertinent to their needs and can be equipped to apply them to different teaching contexts.
3. As a large group, we then considered ways in which different disciplines might make use of the Toolkit's practical case studies, supporting teaching materials

and guidance articles. Real-world examples of how these tools have already been used were described.
4. Following these examples, participants worked in small groups as they were coached through methods for embedding a Toolkit resource in their teaching.
5. Finally, attendees were given the opportunity to consider how they might adapt a resource or create a new one for their own discipline/programme.

4. RESULTS OF THE WORKSHOP

This workshop emphasised the need to embed ethics into the engineering curriculum, highlighted that behaviours such as inclusivity and sustainability must become instinctive – golden threads running through everything that engineers think and do – and posited that engineering programmes must be proactive in bringing engineering ethics to the fore in order to equip future engineers with the skills and mindset they need to succeed.

The workshop, in which over two dozen engineering educators from around the world participated, showcased the Engineering Ethics Toolkit and introduced a pragmatic approach to integrating ethics content into teaching, using examples and a detailed and interactive curriculum map, which connects the elements of the toolkit.

During the workshop, participants had the opportunity to:

- Consider the contemporary context of engineering ethics education amidst current issues such as AI, net zero, and inclusive design;
- Develop a practical understanding of new resources in engineering ethics education, namely case studies and relevant teaching activities, guidance articles and an interactive curriculum map;
- Reflect on examples of ethics teaching practice in a variety of UK university engineering programmes;
- Engage with pragmatic approaches to integrating ethics content into their teaching through sample activities; and
- Create a new engineering ethics resource suitable for inclusion in their module/programme.

To help educators to know and use the toolkit the workshop was an attractive translation of engineering ethics teaching theory to the practice of engineering education at a time when an ethical approach to engineering practice is essential to a more sustainable and just future.

Workshop participants took away high-quality open-source engineering ethics teaching resources and pedagogical strategies that enable engineering students to be able to identify ethical issues, exercise ethical thinking and use ethical judgement within their projects and coursework.

5. CONCLUSIONS

This is an ongoing piece of work to support the sector and the workshop helped to embed the Ethics Toolkit as a regular component of engineering teaching and highlighting excellence in integrating ethics.

The workshop acted as a seed to encourage further case studies to be developed and an exploration of what can yet be done in this space to ensure the next generation of engineers are well-equipped to address the ethical issues they face.

Additionally, the workshop bolstered an emerging community of practice that has been established to encourage, support and acknowledge good practice in engineering ethics education.

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The toolkit can be found at: https://epc.ac.uk/campaign/engineering-ethics/.

HOW TO USE NEW TOOLS TO INTEGRATE SUSTAINABILITY INTO ENGINEERING TEACHING

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ABSTRACT

Recently, three projects have addressed the challenge that while many excellent resources on sustainability education exist, there aren't many that explicitly guide engineering educators to integrate these into their teaching, or indeed that are intended to upskill engineering academics to be able to deliver this teaching. These projects are the Reimagined Degree Map project undertaken by Engineers Without Borders UK (sponsored by the Royal Academy of Engineering), the Sustainability Toolkit project undertaken by the UK's Engineering Professors' Council (sponsored by Siemens and the Royal Academy of Engineering), and the Engineering for One Planet Framework and two companion guides, co-created by hundreds of engineering education stakeholders (sponsored The Lemelson Foundation). All aim to build the capacity of educators to embed sustainability knowledge, skills and

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mindsets in their modules, courses or curriculum that will enable students to become competent in globally responsible engineering practice. In cooperation with academic, industry, and advocacy group leaders, these projects have resulted in the development of several educational tools that are presented in the workshop.

1 INTRODUCTION

1.1 Motivation

Have you wanted to embed sustainability in your engineering modules but are unsure how? Do you want to gain confidence in equipping and motivating your graduates to tackle the serious sustainability challenges facing the environment and society? This workshop will introduce new tools designed to help engineering educators more easily and effectively integrate the sustainability knowledge, skills, and mindsets that both students and employers are demanding and that are essential to the globally responsible practices society needs today. This session is relevant to engineering educators of all disciplines and backgrounds in higher education, as well as administrators and programme leaders responsible for accreditation and/or curriculum development.

1.2 Workshop Learning Outcomes

Following the workshop, participants will be able to:

- Access three new tools for integrating sustainability into engineering education and explain the relevance of these tools to their module/programme;
- Identify key sustainability competencies that engineering students should develop and understand methods for incorporating these into technical learning;
- Introduce these tools to their colleagues and advocate for their use.

2 BACKGROUND AND RATIONALE

The Institute of Engineering and Technology reported in 2021 that of 1,000 UK engineering companies with a sustainability strategy, only 7% have staff with the skills to fulfill it (IET 2021). At the same time, Surveys conducted by Siemens as well as the UK organization Students Organising for Sustainability have revealed that 79% of students want to see sustainable development incorporated and promoted in all their courses, and while students view real-world activities as most useful in learning about sustainability, only 22% had this experience in their first year engineering courses (Siemens 2023; Students Organising for Sustainability 2021).

Therefore, the need to integrate sustainability as an explicit and essential component of engineering education has never been more urgent. Global engineering education organisations, national accreditors, students, and many industry groups now advocate for sustainability learning to form a critical part of engineering curriculum (Engineering Council 2020; Students Organising for Sustainability 2021; Standish, Smyth, and Zambrelli 2020). Yet engineering academics themselves have not necessarily been trained in education for sustainability, and they may not feel they possess the experience or confidence to weave this learning into the modules that they teach (Savage et al. 2015). Additionally, it can be overwhelming to sort through the abundant guidance available on sustainability education and to determine what fits best in engineering education.

3 WORKSHOP SESSION DESIGN

This interactive workshop will introduce these new resources, giving attendees a chance to learn about them as well as to plan how they could be implemented in their own educational contexts.

First, workshop participants will engage in a facilitated large group discussion on the current context of sustainability in engineering education at the programme, institution, national, and global scales. This discussion will also address inputs from students (via outcomes from the Siemens Skills for Sustainability Student Survey) and industry (via engagement with professional engineering institutions and companies conducted by Engineers Without Borders UK). This activity will provide the background understanding for why these resources are important, and why engineering education must change in order to incorporate sustainability learning.

Second, participants will be prompted to consider how changes within engineering curricula can be enacted by module and programme leaders. The Reimagined Engineering Degree Map will be presented as a way to consider the broader purpose of strategies to deliver sustainability. Participants will explore interventions educators can make to learning journeys and design relevant learning opportunities that enable the integration of sustainability at different levels.

Next, participants will have the opportunity to learn about the core and advanced student learning outcomes found in EOP's "Tools for Teaching and Learning" (Engineering for One Planet) that are aligned with ABET accreditation standards, the UN SDGs, and Bloom's Taxonomy. Participants will learn how they can integrate and apply the learning outcomes into their own module or programme by leveraging two companion teaching guides that provide specific sustainability-focused teaching and learning materials available for free and online to everyone.

Finally, participants will be guided to reflect on existing good practice and where gaps remain in implementation. This reflection process will in turn inform other resources under development for the Sustainability Toolkit in the areas of understanding, integrating, assessing, and collaborating around sustainability skills and competencies.

4 RESULTS AND IMPACT

The hope is that the workshop will encourage and initiate uptake of these educational tools. This will in turn lay the groundwork for further research on the practice of embedding sustainability within engineering education, as well as provide guidance and support for educators in this process. Educational tools are only effective if they are implemented, iterated on, and continually improved, so another outcome for the workshop will be to discuss opportunities for establishing an international community of practice dedicated to using, promoting, and further developing these resources.

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ENHANCING RETENTION AND TRANSFER IN MATHEMATICS IN ENGINEERING EDUCATION PRACTICE

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ABSTRACT

This article is a reflection of a SEFI workshop on Retention. In the workshop, a SWOT Analysis has been realised of four pedagogical solutions addressing Retention in undergraduate STEM education. The pedagogical solutions are programmatic assessment, micro-credentials for online mathematics (support) learning modules, autonomous and self-regulated learning and mathematical competencies for learning. Results have provided insights into the relevance and feasibility of implementation.

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1 INTRODUCTION

1.1 Retention and Mathematics

Mathematics is at the heart of the engineering curricula and is instrumental in the engineering profession. However, one of the significant problems of engineering education is the dropout rate.

It is presumed that too little practice in mathematics creates a shallow and memorised understanding of the reasons behind calculations, and mathematics cannot be transferred. To understand mathematics, one must often practice connecting visual and symbolic representations to acquire numerical or mathematical fluency (Boaler et al., 2015).

Arguably, difficulties in higher education start in secondary school, where mathematical competencies are less developed than needed for tertiary education. To succeed in higher education, students should dedicate six hours a week to mathematics (van den Broeck et al., 2019). A criterion that is not always met. Additional stumbling blocks are caused by the many foundational mathematics courses at the start of the bachelor programme. Treacy (2016) found that these BSc mathematics courses cause a high dropout rate. As many as one-third of the student population entering STEM education fail the foundational Mathematics courses. An area for improvement is the epistemological difference between foundational mathematics and any engineering disciplines like mechanics, which typically use different symbols, representations or framings of a problem that are not or only partly compatible. It makes it difficult for higher education students who fail to recognise and know what mathematics to apply in engineering contexts. The Mathematical Competencies framework and identifications of mathematical competencies across disciplines and domains might support the cross-epistemological compatibility of mathematics in engineering (Alpers et al., 2020).

Several measures are available to mitigate the negative impact of these discrepancies, such as timely feedback, programmatic assessment, micro-credentials and learner autonomy and self-regulation. Regular and timely feedback should be used to repair any potential misconceptions or misunderstandings, adapt inappropriate learning process mechanisms or missing self-regulation activities. Effective feedback should include feed-up feedback and feed-forward mechanisms and be completed on time (Hattie & Timperle, 2007; Morris et al., 2021). Programmatic assessment and micro-credentials are two means to achieve more time on task and timely feedback (van den Broeck et al., 2019; Baartman et al., 2022). Finally, students must increasingly work autonomously and independently on the mathematics practice materials. In Covid times, we found that students highly appreciated a higher level of autonomy and felt it supported their well-being (Cristea et al., 2021). This autonomy should equally reinforce their capacity for self-directed or self-regulated learning (Schweder et al., 2022)

High shortages in STEM graduates ask for mitigating these effects worldwide as UNESCO shows mounting shortages. Creating Service Mathematics Education (SME) with the highest possible passing rate and designing it in order to enhance transfer (from mathematics to engineering and from mathematics to subsequent mathematics courses) is of the utmost importance to keep, sustain and retain as many students as possible to continue and successfully finish their engineering education.

1.2 PRIME Mathematics Education

At TU Delft, the large-scale programme of innovation in mathematics education (PRIME) has been focused on this idea for the past few years by introducing a blended learning programme for SME in which "Prepare, Participate, and Practice" is at the heart of the didactical model, activating students as much as possible towards satisfactory learning results. However, more than PRIME is needed to realise the wished-for success rate in engineering. To mitigate the low retention and looming shortages, TU Delft intends to set up an alternative support structure focused on the following:

1. Programmatic assessment (Baartman et al.,2020), making regular and formative assessment central to signalling failure and timely feedback and support to reduce dropout.
2. Micro-credential support programme, embedding online in offline education.
3. Increased autonomy for students, allowing for greater satisfaction and self-directedness in learning.
4. Using Mathematical Competencies to bridge the gap between SME and Engineering.

We are investigating the typical problems and issues in SME, the causes for low retention, and what typical shortages create barriers that limit the transfer from Mathematics to Engineering.

1.3 Workshop Assignment and Methodology

This workshop is intended for scientists and lecturers who teach mathematics and engineering. Participants are invited to interactively create a SWOT analysis of the proposed solutions. The workshop briefly introduced the theoretical foundations of mathematical learning problems in higher engineering education. Each table had a handout with "the problem definition," included in Fig. 1 and a brief theoretical explanation of one of the solutions to be addressed. Successively, the participants (teachers/researchers) attending the workshop were asked to tap into their tacit knowledge of engineering and mathematics. To make this implicit knowledge explicit to the two communities present, the participants jointly performed a SWOT analysis and presented the results to one another.

"*In an open discussion you are asked to make a SWOT analysis of one of the four approaches with the open question "To what extent does the approach meet the ambitions/solutions laid down in the formulations of the problem*?" (Fig. 1).

Formulation of the Problem

One of the major problems of engineering education is the dropout rate, often instigated by a high number of foundational courses at the start of the bachelor programme. It is stated that these may cause as high a drop out as 1/3th of the student population entering STEM education. High Shortages in STEM graduates ask for mitigating these effects. Creating SME with the highest possible passing rate is of the utmost importance to keep, sustain and retain as many students as possible to continue and successfully finish their engineering education.

The PRIME Service Mathematics Education programme has been focused on this ideal the past few years by introducing a blended learning programme in which Prepare, Participate and Practice are at the heart of the didactical model, activating students as much as possible towards sufficient learning results. However, it is found that Prime in itself is not enough to realise the wished for success rate in Engineering. We have observed a passing grade fails to consolidate the mathematics transfer to the engineering disciplines. Students, who are spending insufficient time on task cause and unsurmountable backlog, and might have passed if they did dedicate their time on task.

To turn the tables we came up with a PRIME support programme which is called RETAIN and consists of a number of activities to keep students in the engineering programme. These are:

- Create an early warning system for potential failure.
- Create programmatic assessment in which low/high stakes assessment is well-balanced and offer the opportunity for extensive feedback and progressive learning.
- Create an online programme based on math compencies (and accredited with micro-credentials) and supported by offline on campus tutor groups.

The goal is to make students

- Aware of their progress by giving student timely feedback both through feedback and assessment
- Strive for autonomous and life long learning skills development
- Aware of their highest potential in the acquistions of Mathematics for Engineering
- Able to transfer the mathematics competencies to engineering/real life situations.

To realise these ambitions we intend to make use of a number of didactical approaches, which are useful to shape supportive activities.

Fig. 1. Handout formulation of the problem for workshop

The workshop concluded with a general discussion of the solutions proposed by the audience during the workshop, testing the validity of the intended solutions developed by the authors. We expected to validate and expand on the solution space for increasing retention and supporting the transfer of Mathematics to engineering education.

2 RESULTS SOLUTION SPACE INQUIRY

2.1 The Solution Spaces

The workshop participants were devided in four groups. Each received a hand out with background information on a particular solution and the hand out of the problem definition. Included below arethe solution spaces incorporated in the hand-outs for discussion and the SWOT analysis that has been made based on the discussions and presented in the workshop.

2.2 Programmatic assessment

Programmatic assessment (Baartman et al., 2020), making regular and formative assessment central to signalling failure and timely feedback and support to reduce dropout. It is a new assessment format that has been introduced by van der Vleuten, Baartman & Schild-Mol in Dutch Higher Education. Its key principle is to make the entire growth of the student learning process visible via reliable and regular feedback tools and assessment. It provides actionable feedback, evidence of development across courses, benchmarking against learning objectives at (year/programme level) and informs remediation efforts needed to overcome gaps in student learning. The programmatic assessment does not know one type of format or way of doing things but knows many ways of realising its goals. However, a few key principles have been identified to guide the orchestration of the learning environment in one emblematic of programmatic assessment.

These principles are:

1. creating insight into the development of the student as results of different data mix of (input) points
2. each measure moment includes a feedback moment to show where the students should focus on
3. a continuous dialogue is in place to provide students with feedback for self-regulated learning development.
4. assessment is weighted, balanced and in accordance with the stakes of materials assessed.
5. the needed assessment expertise is adapted in accordance with the (high or low) stakes of the assessment.
6. validity and reliability of assessment quality are established across the entire assessment programme).

The learning outcomes are the backbone of a programme steering the multiple and balanced input points of the overall student performance towards the final requirements.Together they are offering the basis for a holistic activity and provide an assessment plan guiding the learning process.

Table 1. SWOT results programmatic assessment

Strengths	**Weakness**
• Reduce assessment load • Gives more opportunities to practice, receive feedback and demonstrate competence • Spaced assessment works well with retrieval practice	• Does not assess foundational competency in knowledge/skills - focus on higher level integrative skills • Does this just kick cramming down the road • Removes incentive to learn within term
Opportunity • Point to assessment or application in future courses • Creating folder/library of case studies and examples that can be integrated • Split teacher workload into separate teaching and assessment line items	**Threat** • Overcrowded students • Does it constrain study flexibility • Extra teacher workload: goes from semester limited to one year

2.3 Micro-credential support programme; embedding online in offline education

The PRIME curriculum for SME in Engineering was developed in 2017. It is a blended learning programme aiming to increase academic success, strengthen the transfer of mathematical skills to engineering, and increase engagement and participation in class via the model of prepare, participate and practice. The programme is implemented with success in x faculties across TU Delft (Cabo & Klaassen, 2019). Currently, however, with the changing environment of Higher education and increased urgency to address new developments, the programme requires improvements. These improvements are concerning, notably, the "time on task" of students, flexing the dedicated work time of students on SME and building cross-disciplinary learning communities on mathcore competencies. New technologies offer the possibility to embed online supportive micro-credit courses into the regular programme.

Micro-credentials are measurable, comparable and understandable with clear information on learning outcomes, workload, content, level, and the learning offer, as relevant. They should be designed as distinct, targeted learning achievements, and to meet identified learning needs. Compared to full-length courses, micro-credentials also offer a more personalized, on-demand learning experience. And, unlike traditional degrees, which take years to complete, micro-credentials can be completed in weeks or even days.

Offering small (cross) disciplinary (face-to-face) working groups to do additional and facilitated practice training while working on the micro-credentials will support students in establishing the needed level of "mathematical competencies". Additionally, it will allow students to refresh old knowledge when preparing for engineering courses and benchmark themselves against the required knowledge levels in Engineering Education.

Table 2 SWOT results mico-credentials

Strengths	**Weakness**
• Series of MC (refresher course) helps to bring students on the same mathlevel • MC's reactive to missing skills/competences • MC's of different size/credit • Packaging/high accessibility-> individual learning path	• Depends on self-motivation, so success is not sure • Scaffolding/interconnection of MC's is not ensured
Opportunity	**Threat**
• Not obligatory/mandatory • Opportunity to gain credits. • Confidence gained by attaining a sense of achievement upon completion plus through interaction with other cross-discipline students. • Archive knowledge	• MC does not provide the full picture. • Engineering students might not make the connection between credentials … and application.

2.4 Increased autonomy for students; Satisfaction and Self-directedness in Responsible Learning.

Learning in the Higher Education Context is said to occur when the learner can do or knows something not known before, and them are able to demonstrate the learned task on demand, independently and to a satisfactory level (Sadler, 2010). Creating autonomous engineers capable of lifelong learning requires continuous and independent judgement of the level of work delivered and whether this is good enough in a particular context. Evaluative judgment is determined by different aspects such as context, quality, standards, and assessment criteria (Fischer et al. 2023). Context is the disciplinary paradigms (ways of working) students should know. This context allows students to develop results that contain suitable characteristics for a particular (disciplinary) domain. Quality and standards allow the students to be aware of what makes a good quality performance defined by specific standards. This continuous and independent judgement of (professional) performance is called evaluative judgement. Students are expected to become more self-directed in their learning and obtain more insight into what they are capable of in mathematics or still need to learn, as well as how it translates to the engineering curriculum. A secondary spin-off might be that students will become more motivated as they become more autonomous in their learning (Cristea et al., 2021) and experience more well-being due to increased flexibility in the curriculum. Thus, evaluative judgment is the capacity to judge the work of oneself and others, which implies developing knowledge about one's assessment capability (Fischer et al.2023). According to Sadler (2010), it would require the development of substantial evaluative experiences in Higher Education Teaching contexts to enable students to acquire tacit and explicit knowledge that will help them to recognise and judge the quality of their own and other work when they see it. Only then can the learned be demonstrated independently without support. This group came up with a solution within the frame of autonomous learning and made a SWOT on *‘ a mandatory course like “learning to learn” fostering selfregulated learning (SRL)’*

Table 3 SWOT Results- Self Regulated Learning

Strengths • Transferable skill	**Weakness** • Align with teacher, adapt to courses
Opportunity • Mandatory-> for all students -> develop and improve the course	**Threat** • Retention of learned SRL skills • Workload for students and teachers

2.5 Using Mathematical Competencies to bridge the gap between SME and Engineering

The Mathematical Competency Framework is developed by Alpers and Holgjeard (2020) and offers a set of 8 competencies representative of Mathematics learning outcomes across different levels of performance in Education, ranging from secondary to higher education. Some studies have been done by the SEFI sig Mathematics in Engineering education and can be found on their webpage. The framework as a tool will provide a solid basis for formative feedback as each mathematical competency allows for setting goals where am I going (feed up), how am I going (feedback), and where am I going next (feed-forward) on the

- Task level (how well the task is understood),
- Process level (what process is needed to perform a task),
- Self-regulation (directing one's actions) and
- Self -level (personal evaluation and affect about individual learning)

following Hattie and Timperley's (2007) model of feedback. Furthermore, the mathematical competency framework allows for curricular design, calibrating secondary, SME and engineering education mathematics programmes. In this project, we will start with the SME in support of the Engineering Sciences, in which four faculties will be involved. The curricular design will be realised in close collaboration with teaching staff of the different engineering departments and mathematics teachers, as well as the involvement of students to make it apt for the local contexts. Eventually, the conceptual model of embedding (mathematical) core competencies in education as guiding framework for flexibilisation can be extended and used elsewhere.

Table 4 SWOT Results – Mathematical Competencies

Strengths • The four levels of feedback focus are highly appropriate, with support for mathematics understanding as well as helping students to develop as learners. Great! • Collaboration between the mathematics	**Weakness** • Appropriate combination of digital (automated) feedback and 1 on 1, personal feedback

teacher and those teaching the engineering courses! • Allows for long term learning goals	• Try to understand the situation from the students' point of view (qualitative understanding) • Since a passing grade does not imply required understanding, consider how the mathematics courses are assessed. • Mentoring activities during course: o Small task to meet teacher/assistant o Follow students progression
Opportunity • The problem formulation does not really capture the aim,"highest possible passing rate" should be replaced with "the necessary and active mathematics competence and skills and self-awareness to learn" • Adaption to different study programs seems not be an option? That could make math feel more relevant to students	**Threat** • Requires a lot of collaboration over a long time, can be hard to sustain for teachers •

2.6 Reflection on Results

In proposing these solutions for retention and transfer, key areas of attention were increasing the time on task and creating bridges between mathematics and engineering. In realising the SWOT analysis, the participants have shown us that programmatic assessment, micro-credentials and the mathematical competencies framework with feedback might be the most effective for retention. However, at the same time, the feasibility of effectively embedding this measure is questionable. It raises issues with the quality/assessment of the acquired knowledge, study load and overcrowdedness of curricular programmes, not to speak of the staff load and pressure to maintain a parallel or integrated programme. The good news is that cross-boundary work amongst teachers and students is facilitated through each of these solutions, allowing for flexible learning, long-term goals, building a case archive and more practice opportunities. These benefits suggest that transfer from mathematics to engineering may be stimulated but is not guaranteed.

Autonomous learning might be stimulated by better-guiding students in learning to learn. It is an important skill to acquire for later professional life. However, it also requires a different kind of teaching, as sustaining it is not a one-sided affair. The teacher must re-educate and grow different students and students' behaviour into scientifically rigorous and creative learners. Finally, the participants urge one to consider carefully how to ask the right questions and solve the right problem. One cannot solve this puzzle by focusing solely on memorisation or understanding. From educational research, we know that memorisation involves the process of encoding information into one's memory, aiming to retrieve it correctly later. Understanding, however, requires students to make sense of existing knowledge and integrate this knowledge in a meaningful context (Kirschner et al., 2006). It is assumed memorisation is improved by repetition, but independent from understanding, it leads to students failing to apply knowledge in new contexts and problem-solving situations. When students also understand the material, the likelihood of encoding it in long-term memory increases, allowing for easier retrieval. The pair memorisation and understanding are equally essential in learning, where memorisation, increases retention and understanding, improves comprehension, and application (Wang et al., 2017).

2.7 Limitations

This workshop aimed to unearth tacit and theoretical knowledge. However it is not meant or conducted as scientific study. Rather as a pragmatic exchange of information. The results in this paper should be weighted and considered as such.

3 CONCLUSION

In this workshop we presume participants have explored the barriers and problems encountered in service mathematics, and math in engineering and the transfer between those fields from their respective and experienced perspectives. The workshop has offered four choices which have been reported about in the literature to contribute to mathematics learning and transfer. These were programmatic assessment (Baartman, 2020), time on task via micro-credentials (van den Broeck (2019), Baartman (2020), mathematical competencies (Alpers, 2020) and autonomous and self regulated learning (Wallin et al.2018, Cristea et al. 2021). Participants have responded to these four solution spaces and contributed from their experiences about the applicability and relevance of the solutions through a SWOT analysis. Programmatic assessment, time on task via micro credentials and mathematical competences are seen as potentially relevant methods to achieve a higher retention. These methods should support memorisation and understanding, albeit a lot of drawbacks are present and implementation feasibility is questioned. Autonomous and self-regulated learning are seen as key-skills towards a better acquisition of Mathematics in Engineering Education and should be taught irrespective of the retention dilemma. The exchange contributed to a better insight in the pro andcons of pedagogical measures in Engineering Higher Education practice.

4 SUMMARY AND ACKNOWLEDGMENTS

We would like to expressively thank the participants for their invaluable contribution to a longstanding and ongoing discussion in Engineering Education.

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Teaching in student-centred active learning spaces: How relational, pedagogical, spatial, and technological aspects intertwine and affect the learning environment

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Motivation and Learning Outcomes

Higher educational institutions internationally have shown a growing interest in developing learning spaces that support student-centred learning approaches. For engineering education, this development aligns well with an increased emphasis on cross-disciplinarity and a system-thinking approach. However, research and our own experiences as teachers and evaluators of such learning spaces suggest that teachers who enter these learning spaces need support, as the complexity of the teaching situation becomes more apparent, compared to the traditional lecture hall. In this workshop, we will investigate this complexity together with the participants.

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Participants can expect to leave the workshop with a better understanding of:

- a conceptual framework that will assist the participants in navigating through the complexity of teaching in student-centred learning spaces.
- how to plan, implement and evaluate one's own teaching in such learning spaces (Do's and Dont's).

The take-home message from this workshop is an appreciation for how the relational, pedagogical, spatial, and technological aspects intertwine and affect the learning environment in spaces designed for student activity.

Background and rationale
Higher educational institutions internationally have shown a growing interest in developing learning spaces that support student-centred learning approaches. This increased interest can be explained by a variety of factors: For one, institutions need to optimize the use of their limited physical space. usage of campus. Furthermore, traditional higher education institutions are grappling with the challenge of maintaining a vibrant campus in an increasingly digital world, and attractive learning spaces coupled with appropriate teaching and learning activities might play an important role in this respect. Finally, the emergence and development of these learning spaces have followed an increased awareness among faculty of the potential associated with student-centred and innovative teaching and learning approaches (e.g. Freeman et al., 2014).

However, the emergence of these student-centred learning spaces has elucidated the complexity of the teaching and learning situation, as both teachers and students are expected to take on more involved roles in these learning spaces. The complex interdependence between spatial, pedagogical, relational, and technological aspects and affordances become more tangible, compared to the traditional lecture hall. Our observations suggest that teachers and students who enter these spaces need support, in order to adapt to these new roles. We follow Leijon et al. (2022), who state that: "Space cannot be isolated as a single cause to positive learning outcomes, but people, space, interaction and learning are intertwined" (p. 15). One conceptual tool in this respect is the Pedagogy-Space-Technology (PST) framework, developed by Radcliffe et al. (2008). This framework emphasizes the interdependence of pedagogy, space, and technology – which is of critical importance concerning development and appropriate use of such learning spaces. It suggests that the design of effective learning spaces requires consideration of not only the pedagogical approach being used but also the physical space and technological tools that will support the learning process. The PST framework offers a holistic approach to designing learning environments.

Workshop Design
In this workshop the participants will actively engage in discussions of how to use learning spaces designed for student activity. The outline for the workshop is as follows:

- A brief introduction, where we focus on student-centred learning spaces in general: typical technological, spatial and infrastructural affordances associated with these types of spaces. (15 min)
    - This introduction will be exemplified with visual representations of different learning spaces, which we will examine together with the participants.
- Participants are divided into small groups, where they will draw upon their own teaching experiences, discussing how and to what extent the different learning spaces could facilitate their students' learning processes. (15 min)

- Our team will facilitate these group discussions, and we hope to gain answers to questions such as (15 min):
    - What is the teacher’s role?
    - What do we expect from the students?
    - How should we facilitate for learning, and what are our responsibilities?
    - What are the potential opportunities and constraints of these spaces?
- The workshop is finalised with a plenary discussion where we summarise the group discussions. (15 min)

Results of the Workshop 2-04, 8:00 – 9:00 Tuesday, 12. September 2023
In the workshop the participants were asked to choose the learning space they would prefer, both from a teacher’s perspective and a student’s perspective. The distribution of their choices is shown in Figure 1, where blue notes indicate the teacher perspective, and yellow notes indicate the student perspective.

Fig. 1. The participants preferred Learning spaces as teachers (blue) and students (yellow).

In the group discussions that followed, the teacher’s role and design of effective learning processes in these learning spaces were central. Finally, the participants discussed Do’s (green) and Don’ts (pink) regarding utilizing spaces designed for student activities. The results from the groups are shown in Figure 2.

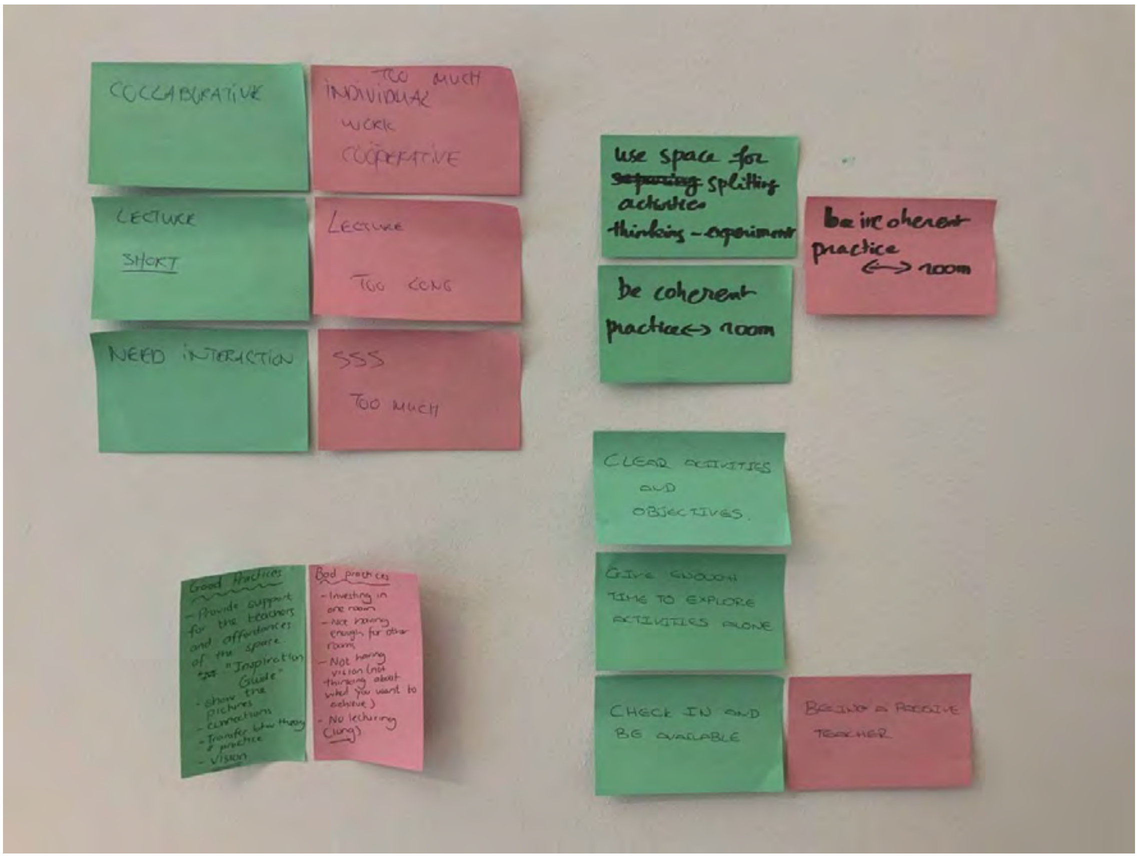

Fig. 2. Do's and don'ts results from group discussions.

Significance for Engineering Education

As engineering education is moving toward emphasising cross-disciplinarity and a system-thinking approach (Crawley et al., 2014), there is an increased need to facilitate a study culture where students work actively in collaboration with each other to solve authentic problems, where the teacher takes on the role as a facilitator for the students' learning processes. In this perspective, the space and the infrastructure surrounding the students' learning processes become important.

Over the years, our own university has developed a range of student-active learning spaces specifically designed to facilitate student-centred teaching and learning in an engineering context. These spaces are designed with a variety of collaborative features such as group stations, work surfaces, and technology. Our team has extensive experience in utilizing, improving, and evaluating the affordances of these spaces, and we have been involved in instructing teachers on the pedagogical use of these spaces.

Both during and after the workshop we experienced interest from the SEFI-community regarding learning spaces and pedagogical aspects. Many Institutions in higher education, are working on these issues, and how to design learning spaces for student centred activities.

Acknowledgements

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STRUCTURING CONVERSATIONS AROUND COURSE DESIGN

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Keywords*: constructive alignment, course design, visual tool, conversation*

WORKSHOP ABSTRACT

Constructive alignment helps both students and teachers to achieve intended learning outcomes. The workshop proposes to introduce participants to the elements and mechanics of the pedagogical coherence canvas (PCC), a tool developed to improve constructive alignment throughout course design. Participants will familiarise themselves with the process by applying it to the design of a course or training. This hands-on workshop will help participants to develop a practical understanding of how to use the PCC to design a course following constructive alignment principles.

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1 BACKGROUND, RATIONALE AND RELEVANCE

According to the principles of constructive alignment first described in the literature by Tyler (1949) and, later on, by Biggs (1999), an outcome-based curriculum should be designed as a coherent system containing three central elements: learning outcomes, teaching strategies and assessment strategies. At the same time, one sometimes needs to be reminded that teachers are first and foremost experts of content so when they go about designing a course, that's often where they tend to start. Moreover, a course does not take place in a vacuum. Contextual elements, such as the number and diversity of students, the format of the course (in presence or hybrid), the available infrastructure and the teaching staff's experience place real boundaries around course design. Contextual factors can also heavily impact course design. One can think of how the pandemic has abruptly changed teaching formats or how Large Language Models can require some teachers to revisit elements of their course (e.g., in terms of assessment, activities or learning outcomes).

2 MOTIVATIONS AND LEARNING OUTCOMES

Through our experience of Teacher support, we have noticed that integrating content and contextual elements allows them to focus on their immediate concern (i.e., designing a course on a subject) without disconnecting them from the setting in which the course takes place (Hussey and Smith 2002).

Whereas many teachers and pedagogical advisors are familiar with the principles of constructive alignement, some seemed to lack a visual and actionable tool (Avdiji et al. 2020) to ensure constructive alignment throughout the design of a course (e.g., for teachers working alone) or to structure a conversation around course design (e.g., for pedagogical advisors or for teachers in a co-teaching format).

We have developed a canvas to support both teachers and pedagogical advisors throughout the course design process. It builds on the constructive alignment principles and extends them by adding both content and contextual elements to the initial framework. By design, it retains intended learning outcomes at the core of the process while giving explicit space to context and content. The canvas can be used both for creating a course but also for revisiting one, reflecting on its overall alignment or integrating new contextual elements.

At the end of the workshop, participants will be able to:

- Describe the elements and mechanics of the pedagogical coherence canvas
- Apply the canvas to the design of a course
- Reflect on the design process through a structured conversation
- Assess how the canvas can be used to design a course or structure a discussion around course design

3 WORKSHOP DESIGN

The workshop proposes to introduce participants to the mechanics of the canvas and to structuring conversations around course design with the help of a visual tool.

The workshop will proceed as follows:

- Description of the workshop's aim and brief recap on constructive alignment
- Short introduction to the pedagogical coherence canvas with an example from engineering
- Working alone and in pairs, participants will familiarize themselves with the tool and process by applying it to the design of a course
- The workshop will end with a debrief on what worked well and less well in the design process, first in pairs, then in plenary

Participants will be provided with canvases and post-it notes.

Post workshop: The organizers will gather all canvases, provide comments pertaining to the alignment of the canvas produced and share a set of best practices.

4 TARGET AUDIENCE

The workshop is primarily intended for teachers and pedagogical advisors.

Previous experience with designing a course or accompanying teachers in course design is necessary but one does not need be an expert in either one. The same can be said about familiarity with the principles of constructive alignment.

The number of participants targeted is between 12 and 40 – there are in principle no issues of scalability (provided the room is large enough).

Pairs will be constituted on the basis of the audience. Guidelines can be adapted on the basis of the audience's composition.

5 SIGNIFICANCE FOR ENGINEERING EDUCATION

Given its generic nature the canevas can be used in desiging courses both in humanities and engineering. That said, in light of the integration of contextual factors (e.g., inclusivity, openAI, ec.) or importance given to transversal skills, the inclusion of a broader set of variables in course design should not take place at the expense of pedagogical coherence. Mapping a course can help finding an optimal equilibrium between equipping students with the required engineering competences and transversal skills while building on evolving contextual variables.

6 ENHANCEMENT OF KNOWLEDGE AND DIALOGUE

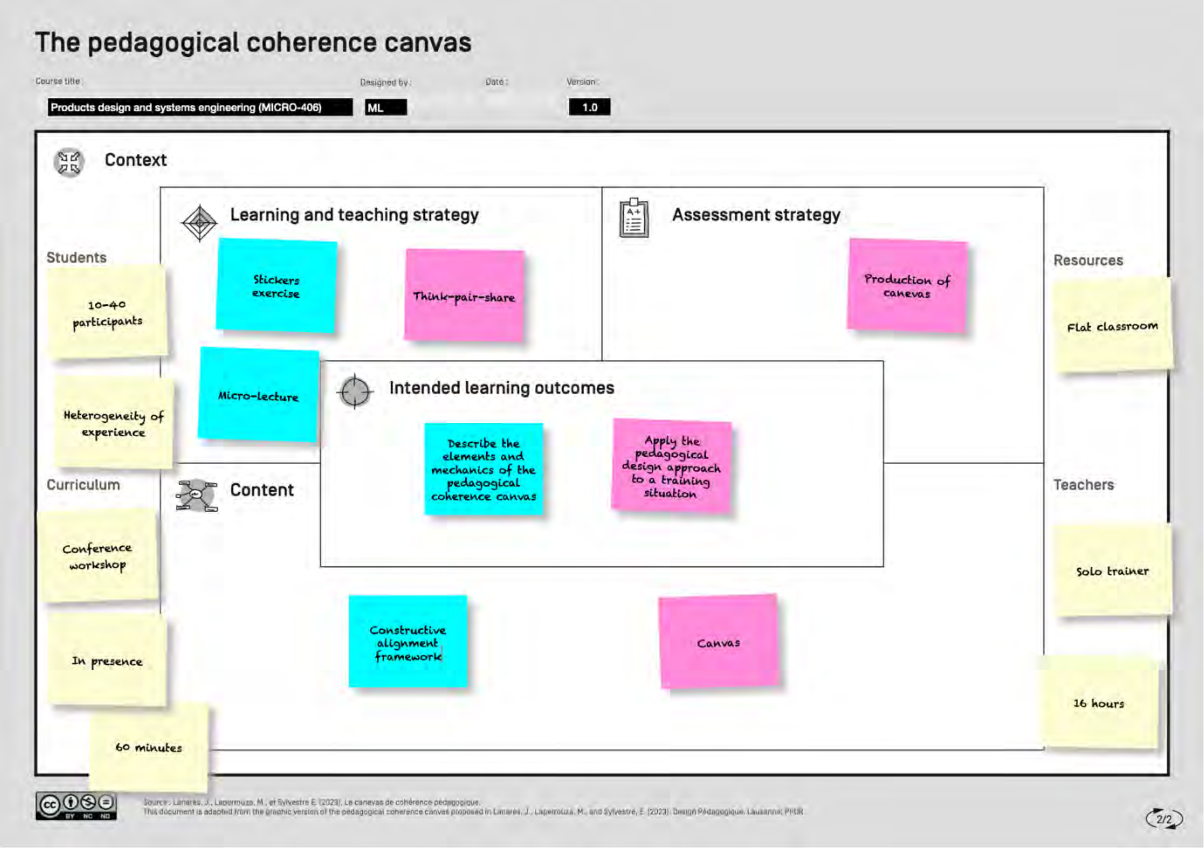
The workshop is designed to provide a short but intensive experience of course design following constructive alignment principles both for new and seasoned teachers and pedagogical advisors. The mix of peer work and exchange followed by a plenary discussion should allow participants both to revisit their practice of constructive alignment and benefit from other participants' experience.

7 REPORT[2]

The 60-minutes workshop was held on September 11 and attended by 37 participants.[3]

After a recap of the aims, a short introduction covered the principles of constructive alignment. This was followed by the presentation of the elements and mechanics of the pedagogical coherence canvas. An example drawn from an engineering class was used to illustrate the use of the canvas.

Participants were then first asked to apply this to the workshop itself. To this end, they were provided with 16 pre-filled stickers and tasked with placing them on a blank canvas individually. The exercise was rapidly debriefed (see below).



Each participant was then given a set of blank stickers and tasked with designing a course on the basis of one intended learning outcome. After 20 minutes they were handed a conversation guide and asked to discuss in pairs one canvas.

The final 15 minutes were devoted to debriefing the use of the canvas and of the conversation guide. A number of comments were made by the participants:

- the canvas provides a useful framework to structure a course, in particular for new instructors

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[3] For users interested, the slides are available here: SEFI2023 Presentation.pdf.

- the visual dimension adds value
- the first stickers exercise is great; it may be interesting to have less "sticky stickers" to move them around

Participants also raised a number of questions or made suggestions as to:

Question/suggestion	**Comment from workshop organizer**
the order in which one proceeds (e.g., shouldn't one start with the core elements rather than the context)	as longs as coherence is maintained throughout, there is no imperative to start with the context; experience has shown that instructors are content experts and often want to start there; depending on the type of interaction/level of seniority, it way well be the starting point to engage a conversation
is the size of the blocks proportional to the importance of the elements; how can one fit all the intended learning outcomes for a semester in such a small space	there is to a certain extent an intention to keep the different blocks relatively small; for a whole semester, this leads to high-level ILOs and bird's eye view of the course (something that is easy to communicate at the beginning of a course to students but also useful for instructors for quickly assessing the feasibility of a course)
whether the canevas could be used in a program/full curriculum development process	nothing prevents bringing several canvases to the table to gain an overview of the different courses and potentially identify overlaps, repetitive learning and teaching activities or assessment modalities; at the same time, there is at this stage no dedicated tool for a meta curriculum development canvas; other tools have been developed to ensure/increase constructive alignment
whether content should be included in the canvas since it is not in the original Biggs' paper	in our experience instructors are content experts and not all of them are able to 'naturally' take a step back and transform content into ILOs or for that matter start with ILOs; as a result, the content block can be useful to initiate a conversation but also to ensure that, for

	a given ILO, there is an appropriate content

In summary, most of the debrief covered aspects related to the canvas and not to the conversation guide. Follow-up discussions during the conference led to a number of additional comments, including:

- the use of a 'paper' guide with an instructor could potentially undermine the credibility of a pedagogical advisor but it would be OK to have the guide on a computer and glance from time to time; this raises the question of the lisibility/UX of the guide
- the type of conversation is influenced by the "forces in presence" - pedagogical advisors will take a different approach depending on whom they have the conversation with; in other words, there is no "one-size-fits-all"
- the small questions (third column) are useful to go more in depth

In conclusion, the workshop seems to have been useful to a number of participants but its ambition (canvas + conversation guide) may have been slightly too high for the available amount of time.

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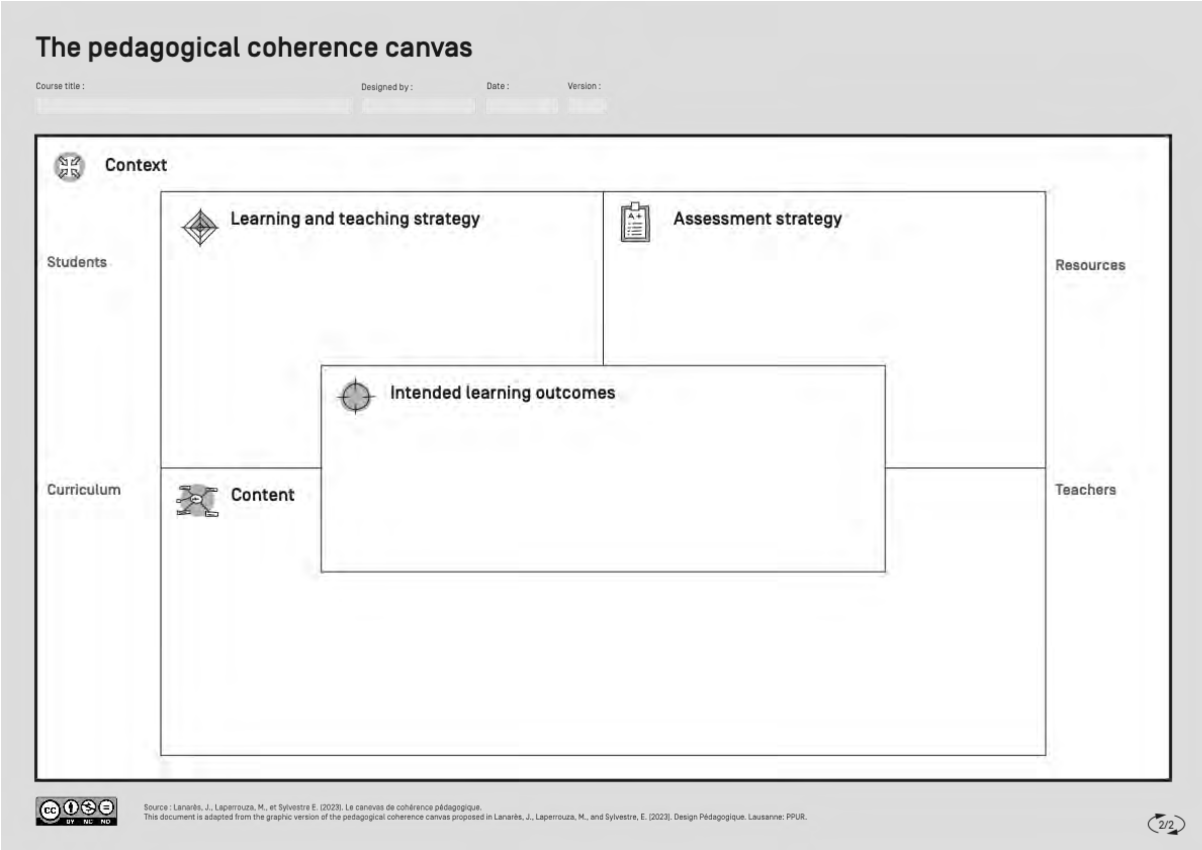
WORKSHOP TIMING

00:00 – 00:05	Introduction and workshop aims
00:05 – 00:15	Elements and mechanis of canvas with example in engineering
00:15 – 00:35	Design a course (think)
00:35 – 00:45	Conversation (pair)
00:45 – 00:55	Debrief in plenary (share)
00:55 – 01:00	Conclusion

CANVAS (BLANK)



Develop an Interdisciplinary Course using the Interdisciplinarity Toolbox

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1. Background: Overview of the Workshop

The ability to engage in interdisciplinary research and problem-solving are essential skills for contemporary engineers, however designing and delivering effective learning opportunities to reach these ideals, is often not straightforward [1]. Educators are often faced with a plethora of challenges, and interdisciplinary courses often do not run as smoothly as disciplinary ones. In this workshop, the primary goal was to stimulate participants to consider a few common design scenarios modeled on real-life cases and to apply some of the main design concepts and questions employed by a new online platform the Twente Toolbox which aims to assist instructors with interdisciplinary course design. Participants were asked to make certain design choices in response to the cases within teams. The toolbox, funded by the Netherlands Initiative for Education Research (NRO) and developed by researchers at the University of Twente (interdisciplinary-education.utwente.nl) maps out different interdisciplinary course design structures, skill targets and learning goals. These are linked to specific in-class student tasks and assessment tools, which help students achieve those learning goals. In the session, participants were directed to relevant sections within the toolbox that would help inform design decisions of participants.

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2. Motivation

Many of us are not fully aware of the scope of alternative course design options and learning tasks that now exist for interdisciplinary education [2]. For example while many interdisciplinary project-based course designs favor open-ended problems for students, student project groups consisting of members from different disciplines and an assessment which puts weight on integration of methods, none of these are strictly necessary for interdisciplinary education and in certain circumstances taking other alternatives may be more fruitful for students. By introducing participants to these design choices participants could become more familiar with choices open to them. The Twente Toolbox - interdisciplinary-education.utwente.nl - both outlines such design choices, and provides the conceptual resources needed to understand them, but also links choices to families of appropriate student tasks. The workshop was thus designed to provide an entry point into the toolbox material and structure, from which participants could go further and begin to apply to other material the toolbox provides.

The toolbox is web-based platform accessible through a browser. The platform is structured around a database linking learning outcomes (in the form of skill targets) to specific tools (students tasks) and to course-design options, such as whether to structure a project task as open-ended or more closed. Tools are drawn from published articles and those developed at the University of Twente. The links are based on tool-designers' own assessments of the relevant learning outcomes (as reported for instance in their papers). Categorisations of skills into families are based on existing educational literature. All concepts and tasks are explained so that users also acquire knowledge while using the tool and the means to use a task easily. In addition, the toolbox provides different guided entry points into the information to help instructors gain access to the most relevant tasks and avoid information overload. For instance instructors can access specific tasks by selecting intended learning outcomes they would most wish to focus on in a course design.

At the same time part of the value of toolbox should be its ability bring together collected knowledge on interdisciplinary education as it exists, but also to introduce novel or little known design options and alternatives. We anticipate many of these will not have be countenanced by many educators and would provoke reflection and dialogue in workshops (including on the broader purposes of interdisciplinary education). At the same time, since the toolbox is open to further design itself, participants have the chance now and in the future to provide their own input on what might be missing, inadequately explained or unaccounted for.

3. Workshop Design

Workshop participants were initially presented with a short introduction which explained the central concepts from the toolbox they would be working with. These concepts were described as follows:

> **Mixed or mono-disciplinary**: do you want groups of students mixed up by discipline or should students stay in disciplinary groups?

> **Integrated or multidisciplinary solutions:** do you want students to achieve integrated solutions – solutions which create novel approaches or require students to step out their disciplines – or is the emphasis on them applying their own disciplinary methods (in an

interdisciplinary setting).

Open or closed problems: should the problem be open-ended or should the students apply certain methods, or achieve certain types of solutions for the project-task .

Workshop participants were then split into group of around five to consider a case by answering the following questions.

- Should the grouping of students for the project-task be mono-disciplinary (split into disciplinary groups) or mixed (inter-disciplinary) and why?
- Should a solution to the project-task be integrated or is a multidisciplinary result fine and why?
- Should the project-task be open or closed-structured (or something in between) and why?

Four different cases were spread out amongst the groups. We give the cases here. Each differ, some substantially, in terms of students involved and the institutional objectives of the course, which prompts instructors to reflect on what the purpose of interdisciplinary education should be in such a case and how it should be structured in way to both benefit students but also meet those institutional objectives.

Case 1:

In order for your faculty to reach the interdisciplinary course targets set by the University, your programme director has requested that your well-established 2nd year Industrial Design Engineering course (15 ECs) ***incorporate 2 other disciplines****; Mechanical Engineering and Industrial Engineering Management. The new extended cohort will now consist of 500 students with a 2:2:1 ratio, i.e. IDE 200, ME 200, IEM 100 students. The original course aimed to train students in real-world and practical aspects of designing a consumer product with sub-modules on product-market relations, graphic design and computational modelling of products.*

Lectures & tutorials fed a team project accounting for 50% of the final score. The project was "sponsored" by an industrial partner who simulated a real product conundrum that students had to solve. The course will carry-on as project-based - structured around a project-task – but you have the license to change how the project task is structured and supported with the new types of students on-board as well.

Case 2:

You have been asked to revamp an established course with a project component. The current context is a single discipline of students within a technical medicine programme which was set-up to be interdisciplinary from the start. Technical medicine students are trained in aspects of traditional medicine, clinical practices, but also aspects of engineering relevant to medical equipment design. Technical medicine students as professionals should mediate between traditional medical doctors, and medical instrument operators, and propose technical-based diagnoses and solutions. The goals of this particular course are to instruct students on anatomy, physiology and pathophysiology of the cardiorespiratory system; as well relevant measurement and imaging techniques of use in clinical cardiology, and the principles underlying their design. Students should then apply their new knowledge to the project to solve clinically relevant technical medical problems, in order to make a diagnosis and to propose therapy in a peer consultation. The hope is that students can integrate medical and technical (engineering) knowledge with clinical planning in their projects and students will be assessed on their ability to do so. The project-task can be designed as you see fit in a way for students to *illustrate these abilities.*

Case 3:

Your university is worried that its students are too siloed in their current disciplines and are not learning to interact which is not preparing them well for the real-world. Most student do not readily have contact with students outside their programme. You have been tasked with designing a novel 3rd year elective course (15 ECs) that can attract students from all programmes within the university. The cohort will be diverse, including engineers, designers and social science students (max 50). The course should be project-based - structured around a project-task – but you have the license to decide how the project task is structured and supported.

Case 4:

Three different groups at a university require instruction on stochastic programming (optimization with uncertainty). Stochastic programming problems is used widely in scheduling and queuing problems. The groups are applied mathematics, civil engineering and industrial and engineering management. As a rational step they have decided to share the course. Courses at this university generally include a project and it is assumed that this course too will have a substantial project component along with instruction. The principal focus is ensuring that all students walk out of the course with adequate stochastic programming skills. You are asked to think about how that project should be designed and what support elements (tasks) to include. It is important to note that although each group needs stochastic programming skills their foci are different. Civil engineers are mostly interested in traffic management type problems; industrial and management engineers in scheduling and supply chain management; and the applied mathematics in more complex nonlinear problems. Programmes want to ensure that the groups acquire and practice these skills.

Participants were advised that they could browse the toolbox (through a link provided: interdisciplinary-education.utwente.nl) if they need some deeper explanations regarding the main concepts. After 40 minutes the groups reconvened for a group based discussion in which group was asked to pitch their solutions to the problem for their case.

As a last action the participants were introduced to the content and various functions of the toolbox platform and shown how they could use it to deeper their designs for their particular cases by attaching skills targets (when formulating learning outcomes) and student tasks. Attention was given to a decision-tree tool on the home page which asks the same questions asked of participants in the workshop and, given their choice, directs users towards relevant students tasks. Finally participants were also asked to provide any feedback they might have on the toolbox when using it in the future.

4. Results of the Workshop

For this workshop there were eight groups in total of, on average, five participants. The cases and questions provoked intense discussion over 40 minutes. Groups thoroughly and genuinely engaged with the case studies presented in the hopes of putting forward sensible design strategies. Groups were able to give a reasoned answer to all the questions, and often went beyond those questions to consider how they might structure their course more generally and plan support to students. We found that the groups mapped their answers to the questions we provided to their case well, rather than relying on any canonical view of how interdisciplinary education should be structured. Groups doing case 2 for instance generally saw the situation as one in which students would not be grouped across disciplines for projects, but within their discipline. Those doing case 4 perceived that the project task should not be widely open-ended but needed to be well-structured so as to support other educational goals. Those doing case 3 however recognized a more canonical interdisciplinary type situation and proposed a mixed groups with open-ended integrated problem-solving. They then proceed to bring their own experiences to bear on how to structure such courses and provide student support. This was some demonstration of the fact that many instructors do have typical experience with case 3 type designs. For the other cases educators were less certain but not unwilling to engage with student support issues.

As such participants acknowledged the value of critically considering such a set of questions at the beginning of an interdisciplinary course design process and the need to adapt designs to fit different situations. They also acknowledged, through exposure to different cases, the need to think actively about the best model or design which allows for each discipline involved to have a meaningful contribution (rather than necessarily leave that always to the students themselves to figure out). They acknowledged that different students from different disciplines can face challenges in this regard (for example social science students engaging with technical students). Following the workshop some participants expressed the view, in personal conversation with our team, that the workshop had substantially opened up their consideration of what could matter in interdisciplinary design situations and how important it was not to automatically rely on any one format.

Further seeing the variety of possibilities helped some groups go beyond the specific course level. Some for instance started to discuss interdisciplinarity at the curriculum level seeing a role for beginning with structured problems and more homogeneous groups earlier in a degree, and moving towards more open-ended problems and mixed groups later in the degree once students were more experienced and grounded in their disciplines. In general groups were reflective on what could be achieved in an interdisciplinary problem-solving context – particularly with respect to integration; and to recognize a tension between requiring students to create novel solutions going beyond disciplinary boundaries, but also to create sophisticated well-grounded solutions. There is a need to be realistic about what students can achieve in interdisciplinary courses.

5. Conclusions

In this workshop we introduced participants to the some of conceptual framework and overarching design questions used by Twente Toolbox to assist instructors and others in interdisciplinary course design. Participants demonstrated to us that they could use these concepts and questions from the Toolbox to make informed design decisions to suit different kinds of cases. This was some endorsement of the Toolbox's goals and structure. We hope the dedicated engagement of the participants in our workshop will help spread the use of the Toolbox across the SEFI community.

6. Significance for Engineering Education

Interdisciplinarity is fundamental in many modern engineering programmes, yet remains difficult to set-up effectively given the many different kinds of situations it might be required. If engineering education is to move forward on interdisciplinary education it is important we develop a diverse understanding of what options are available for training interdisciplinarity, and the various goals one could have for an interdisciplinary course. The Twente Toolbox attempts to provide these. The workshop itself provided an introduction to the content and organization of the Toolbox and a hands-on opportunity to apply these features of the Toolbox to a real-world case. Through broader use of the Toolbox we hope to see in the future the development of novel interdisciplinary course designs.

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Questioning Implicit Assumptions – A strategy for proactively fostering inclusion in engineering activity design

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ABSTRACT

Within discussions of inclusion work in engineering education, calls have been made to shift to a shared responsibility model where all are responsible for proactively fostering inclusive environments. In an academic setting, it is through pro-active design of learning activities that academics can pre-emptively meet the needs of diverse students such that they may feel included. This design work often relies on academics being educated or aware of what is inclusive or exclusive for different groups that have traditionally underrepresented identities and lived experiences. However, academics do not always possess this information. This workshop proposes an approach that asks academics to employ a process-based approach to consider what assumptions underpin the design of a real-life student-centered activity and seek information to challenge those assumptions. Participants will employ this approach as well as a suggested method for drawing on evidence-based practice to consider structural and design changes that may make the activity in question more inclusive.

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1 BACKGROUND AND MOTIVATION

Recent discussions of inclusion work in engineering education have called for a shift to a model of shared responsibility between all parties (Brown, Cheng and Whelan, 2021) (Coley, 2019) (O'Shea et al., 2016) (Brown, Pearson and Rosenqvist, 2020). Through pro-active design or re-design of the learning environments and learning activities, academics can pre-emptively meet a broader range of needs for diverse student groups and thus be more inclusive.

In implementing common inclusive frameworks such as inclusive pedagogies (Florian & Spratt, 2013, Burgstahler, 2009a, Burgstahler, 2009b) or universal design for learning (Burgstahler,2009a, Burgstahler,2009b, Hitchcock et al., 2002), many suggest starting with identifying what is non-inclusive in a planned activity or educational context. However, this relies on academics having a good understanding of what is non-inclusive. This may not always be the case, particularly for marginalized identities and lived experiences have less awareness about how to be inclusive of them. To combat this, we propose a process-based approach that shifts the focus to questioning what assumptions underpin any individual's participation in an educational activity or context. This creates a starting point for further lines of questioning and implementing evidence-based design that proactively fosters inclusion to a broader range of diverse students without the need for prior knowledge.

2 WORKSHOP DESIGN

2.1 Overview

In this workshop, participants will apply a process-based approach to educational activity design. The approach asks academics to proactively consider how said activity may be exclusionary to some students based on their lived experience or identity by asking what assumptions underpin the design and delivery of an educational activity. Participants will be guided through applying this process using a provided a hypo scenario. It will also be discussed how to find out if those assumptions may be exclusionary to different student groups who experience marginalized identities and lived experiences and where appropriate, why those in the scenario are exclusionary. The excluded student groups we will focus on will be those understudied in published engineering education research, including transgender and gender diverse students (Haverkamp et al., 2021) (Cech & Rothwell, 2018), students with disabilities and chronic illnesses (Blaser & Ladner, 2020) as well as students experiencing financial hardship (Strutz, Orr & Ohland, 2012).

The process also asks participants to consider how, through activity design and structural changes, inclusion for these groups may be fostered. Finally, intersectionality will be introduced as a concept to consider and understand the compounding effects of marginalized identity and lived experience.

2.2 Intended Learning Outcomes

In small groups guided by facilitators, participants will:

- Explore a hypothetical student-centered real-life education scenario through the lens of a marginalized group. This includes identifying assumptions in the design and execution of the educational experience and the potential

consequences of these assumptions for the group in question to feel or be excluded.
- Discuss what actions could be taken at an individual and institutional level to pro-actively ensure the scenario is inclusive.
- Hear how inequities may be compounded through intersectional marginalized identities and lived experiences groups.

This workshop is intended as a conceptual discussion of the provided hypothetical scenario. Participants are not required to but are welcome to share their personal backgrounds or experiences. Participants are protected by the SEFI 2023 code of conduct (https://www.sefi2023.eu/code-of-conduct).

2.3 Target Audience

All interested in diversity, equity, and inclusion and/or curriculum design are welcome. No prior knowledge or experience is required. A premise to engage in this workshop is that all minority groups that have equality discrimination protection under Irish law (Irish Human Rights and Equality Commission, n.d.) are valid and deserve respect and inclusion in the SEFI and engineering communities. If you are coming from a different context, we respectfully ask that you consider this in light of recent political and legal events worldwide relating to the rights of some of these groups.

2.4 Enhancement of Knowledge

Enhancement of knowledge is that of the participants' approach to educational activity design. Participants will learn about and apply a systematic process that can be used as part of subject design works at their home institutions. It supports participants in their inclusive thinking through making implicit assumptions explicit, supports them in working through these assumptions to adapt activity design and challenges their thinking about inclusion to be through an intersectional lens. Similarly, participants will focus on case studies from traditionally understudied historically marginalized groups which in many contexts, little advocacy or awareness exists.

3 ATTENDANCE AND EVALUATION

8 SEFI2023 attendees actively participated in the workshop engaging in rich and lively discussions for each activity. 2 small groups focused on unpacking the scenario for students experiencing financial hardship while another group focused on transgender and gender diverse students' experiences.

As part of the workshop, participants were able to share feedback with the facilitators. This feedback will be used to inform refinements to the workshop design for subsequent deliveries. The strategy employed to collect said feedback was inviting participants to anonymously note things done well on green post-it notes and areas for improvement on red post-it notes and leave them in a particular spot as they exited. 7 green things done well post-it notes and 4 red areas for improvement post-it notes were left.

Comments highlighting the things done well noted the workshop design ("*great case study, great structure for interactions, great materials to facilitate*" and "*very engaging*"), the materials ("*the wheel of privilege concept*") and the applicability of the workshop to their own practice ("*easy to do, could see myself implementing this*").

Further, two participants encouraged the facilitators to publish the process at the heart of the workshop and the associated case studies, with one asking to potentially collaborate such that the workshop could be delivered to staff at their home institution.

Areas for improvement noted the potential for more depth to the discussions or faster pacing to the session and suggested assigning people to groups to broaden their horizons. While the former is something that changes with the participant in this workshop, for example the workshop ran over 2 hours the week prior at an internal event where participants felt they did not have enough time to discuss everything they wanted, the latter was a specific design choice to allow participants of marginalised identities or lived experiences self-autonomy to not discuss their identity or lived experience without having to self-identify. Another comment noted "*real question of ethics behind Professor X's planning, regardless of policy*", which perhaps speaks to a need of the session as part of reflecting on what actions participants could take to make non-inclusive activity elements inclusive, to discuss how participants may become advocates for change when they come across practices, they deem questionable. Additionally, a comment noted the room layout as being one that was unfavourable to a workshop. This was outside the facilitators control.

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Using a spiral approach to facilitate engineering research and education embedded in real industry settings

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ABSTRACT

Engineering research and education is often done in collaboration with industrial partners through the Industry as Laboratory (IaL), and Challenge-Based Learning (CBL) paradigms. However, its findings are not always adopted, despite the use of well-established and rigorous research methodologies. Academia employs oftentimes extensive and time consuming analyses, while industry operates in smaller cycles with tangible intermediate results. This can lead to the industry losing interest in the research. The Spiral Approach for Systems Engineering Research (SASER) is an approach that aims to mitigate that risk. This can have a twofold benefit in the industry remaining interested, but also the researcher staying motivated. To apply this approach in practice and receive feedback from a broader audience of people we created the SEFI 2023 workshop entitled: "Using a spiral approach to facilitate engineering research and education embedded in real industry settings". This workshop has the objective of discussing best practices when conducting engineering education and research in collaboration with industry. To achieve the planned learning outcomes, the workshop activities will follow a cycle of learn=>apply=>reflect on provided specific case studies that are developed in order to allow the application of SASER. The workshop was attended by 8 participants that were split into 2 groups of 4 people (the 2nd group further decided to split further into a group of 3 and one individual). The results of

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the case studies and the reflection of the participants in the workshop indicate a clear potential for SASER and are promising for further research and development.

1 WORKSHOP MOTIVATION & LEARNING OUTCOMES

Engineering research and education is often done in cooperation with industry. This is because the practical effectiveness of engineering methods and techniques in industry can only be evaluated in such settings (Falk and Muller 2019). Unfortunately, research findings in this context often fail to be adopted by industry (Muller 2005), despite using a thorough and rigorous research methodology like the Design Research Methodology (Blessing and Chakrabarti 2009) and the Design Science Methodology (Wieringa 2014).

With this motivation, this workshop has the objective of discussing best practices when conducing engineering education and research in collaboration with industry. At the end of the workshop, participants are expected to:

- LO1. Reflect on their work approach in collaboration with the industry.
- LO2. Share concrete actions and examples from their own experience.
- LO3. Learn from concrete actions and examples from the presenters' and the other participants' experience.
- LO4. Contribute to all participants' common understanding of opportunities and challenges of Industry as Laboratory (IaL), Challenge-Based Learning (CBL) and the use of the Spiral Approach for Systems Engineering Research (SASER) when conducing engineering education and research in collaboration with industry.

This workshop's relevance to the Engineering Education community lies on assisting to devise techniques to resolve industry-academia tensions related to supervision of research and education. By using a spiral approach like SASER, either independently or in combination with CBL, a closer fit between academia and the industry needs can be achieved.

2 BACKGROUND AND RATIONALE

Industry as Laboratory (IaL), and Challenge-Based Learning (CBL) are prime examples where academia meets the industry both in terms of research and education. IaL is a research approach that improves relevance for industry by embedding parts of the research in real industry settings (Potts 1993). CBL brings industry challenges to the classroom and to research (Christersson et al. 2022). However, both IaL and CBL face the challenge of aligning traditional academic work with fast-paced industrial processes (e.g., extensive and time consuming analysis, may lead to lost interest by the company). SASER was created by recognizing that (1) industry partners in research or education endeavors are not comfortable with long investigation cycles, and (2) young researchers struggle to turn actionable a set of somehow linear research questions or research objectives. This often reduces the industry interest, creates tension between academia and industry, and weakens the will for collaboration.

SASER is an empirical approach that addresses the aforementioned problems (Bonnema, Pereira Pessoa, and Nizamis 2022). SASER explicitly embraces the reality where research questions are not self-contained and that the work is rather cyclical and not linear. During each spiral intermediate results are created, which deliver value to the industry partners and bring good feedback to the researcher.

This is particularly relevant in the case of design research, where research methodologies like the Design Research Methodology - DRM (Blessing and Chakrabarti 2009) and the Design Science Methodology (Wieringa 2014) depict the research activities in a linear fashion and, although mention feedback loops, do not give further insight on how to deal with them. Furthermore, feedback loops are often considered negative and are related to fixing issues found during the sequence of actions. In the engineering practice, though, modern design processes embrace the positive aspect of feedback loops and sometimes even define the design activities to benefit from it. This is the case of the spiral model, which was first described by (Boehm 1988) in the case of risk-driven software development.

In this context, when comparing SASER to the Design Research Methodology, the idea is that research questions could be partially answered through a set of planned spirals. Specific deliverables are produced at the end of each spiral for receiving feedback, where feedback could be received from the industry partner and or from external specialists, which the case of peer-reviewed journals and conferences. Figure 1 illustrates SASER in comparison to the CBL steps and to the DRM phases, where the main research questions are divided into sub questions, which are answered during each spiral. Intermediate deliverables produced at the end of each spiral allow receiving feedback, which is important to reduce the risk to sufficiently and satisfactorily answering the overall research questions.

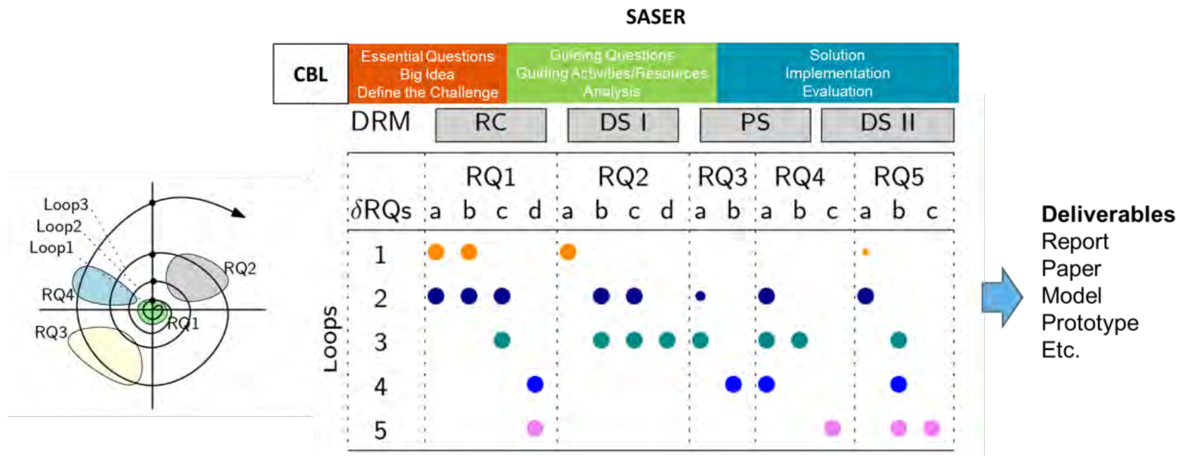

Figure 1. Decomposing the research questions to use the spirals.

To use SASER, there are some pre-requirements to the framed research or challenge. First, there is the need to have a client, which is the industry partner or any other organization or person with vested interest on the research results. Second, the research requires the design of the result, either tangible or intangible. Third, the result to be designed must benefit from decomposition and approaching it in parts. Finally, SASER is not limited to systems engineering but can be applied during any engineering research or project.

3 WORKSHOP DESIGN

This section describes the planned workshop activities and the cases used during the workshop. No previous knowledge was required to attend the workshop, and its target audience includes educators that have interest in working in collaboration with industry, either during education or research.

3.1 Workshop activities

To achieve the planned learning outcomes, the workshop activities will follow a cycle of learn=>apply=>reflect (table 1).

Table 1. Planned workshop activities.

Activities	Activity duration	Learning Outcomes
Learn: The motivation and justification behind SASER is briefly presented, the workshop structure is explained, and the approach is described through an example.	10-15 min	LO1
Apply: The workshop attendees are divided into groups and receive a hands-on task, where they work in a case to define possible strategies to execute a class project or research in collaboration with industry. Although SASER is one alternative, the attendees are also expected to discuss other possibilities. Although sample cases are provided by the workshop organization, the attendees can make use of cases from their own experience. Regardless the choice, the case must include the needs from the industrial partner and the proposed research questions or learning objectives. Depending on the number of attendees, the plan is to have at least three groups, each working on a different case at the under-graduate, post-graduate, or research levels.	30 min	LO2 LO3 LO4
Reflect: The groups will share their experience from comparing SASER with other strategies for collaborating with the industry and highlight their observed strengths and weaknesses. The results of this reflection will be organized and made available to the attendees.	15-20 min	LO4

3.2 Cases used in the workshop

Two cases were offered to the attendees. Purposefully the cases gave the participants the choice between research on creating a product and research on developing a process.

Case 1 aimed at the development of a lean method for planning the lean product development of engineering products. The clients were two manufacturing companies, one from the aerospace and on from the home appliances industry. This research, therefore, is on the area of engineering product development. Its objective is to investigate, develop, and validate a lean product design and development (LPDD) planning method, where lean development encompasses value creation and waste reduction.

Case 1's overarching research question was: How to plan the design and development of an engineering product so that the lean principles of value creation and waste reduction are guaranteed during the project execution? Based on the main research question and objective, a set of secondary research questions was defined.

Investigation questions – these questions help to align concepts and identify best practices and gaps.

- Q1. How are the concepts of value and waste understood in engineering and in project management?
- Q2. Which are the defining characteristics from a product development process?
- Q3. What is the state of the art in lean thinking applied to product development?
- Q4. Which is the state of the art in engineering project planning?

Development questions – these questions breakdown the method creation into major inner processes.

- Q5. How value and waste can be understood in the PDD context?
- Q6. How can all the value and only the value expected from a PDD be captured in the project scope?
- Q7. How can the product architecture be defined so that it embeds all the identified value and reduce the risk of waste?
- Q8. How to define a schedule that guaranteed the value creation and the waste reduction?
- Q9. How to answer questions 6, 7 and using a minimum set of existing tools or techniques?

Validation questions – these questions aim to validate the developed method through different perspectives against the best practices, and to analyze to what extend it fill the identified gaps, it produces useful results, and it is practical to use.

- Q10. To what extend does the method sticks to the identified best practices?
- Q11. To what extend does the method fills the identified gaps?
- Q12. To what extend does the method produce useful results?
- Q13. To what extend is the method practical to use?

Case 2 aimed to investigate the option of developing robotic exoskeletons for the upper extremity to allow people with Duchenne Muscular Dystrophy (DMD) interact with their immediate environment. DMD is a congenital neuromuscular progressive disease affecting mainly males. Modern pharmaceutics prolonged the lifespan of people with DMD, however, the progressive nature of the disease results in lower quality of life and independence. This research, therefore, is on the area of designing a biomedical product for a specific population. Its objective is to investigate, develop, and validate a hand exoskeleton for people with DMD.

Case 2's main goal is "the characterization of the neuro-motor function of the hand, the decoding of hand motor intention decoding and the implementation of this in an active hand support for individuals with DMD." Based on this goal, a set of research questions was defined:

Characterization questions – these questions help to align concepts and identify best practices and gaps.

- Q1. What is the state-of-the-art on medical devices that support the hand function of people with DMD?
- Q2. What is the state-of-the-art in the development of hand exoskeletons in general?

Q3. What is the hand cognitive-motor performance of people with DMD compared to same age healthy people?
Q4. What is the available range of motion of the fingers of people with DMD?
Q5. How can we effectively interface a robotic exoskeleton with people?
Q6. Which of the ways to interface with people, are still feasible for people with DMD?

Development questions – these questions breakdown the method creation into major inner processes.

Q7. How can we effectively decode hand motor intention from people with DMD from the available interfaces?
Q8. How can we translate this motor intention into commands for a robotics exoskeleton?
Q9. Are the identified ways of translating motor intention into robotic commands feasible for people with DMD?
Q10. Which robotic exoskeleton design fits the specific situation of our target population?
Q11. How can we interface with the robotic exoskeleton?

Integration and Validation questions – these questions aim to validate the developed method through different perspectives against the best practices, and to analyze to what extend it fill the identified gaps, it produces useful results, and it is practical to use.

Q12. How can we integrate the previously generated knowledge into a complete system?
Q13. To what extend does the system work and perform the functions expected?
Q14. To what extend does the system deliver value to the patients in practice?

4 WORKSHOP EXECUTION AND GATHERED FEEDBACK

8 participants attended the workshop and were split into 2 groups of 4 people (the 2nd group decided to split further into a group of 3 and one individual). All groups selected case 2 for applying SASER. As a result, three research development plans were made. All 3 groups followed a very similar logic in performing the exercise and applying SASER, however, there were differences mostly attributed to the way each group perceived the problem, the research questions and their hierarchical placement within the overall research context. Although the number of spirals differed slightly, all of them centered each spiral in one or two development questions, where the characterization questions and the selected integration questions were directly related to the development questions (Figure 2).

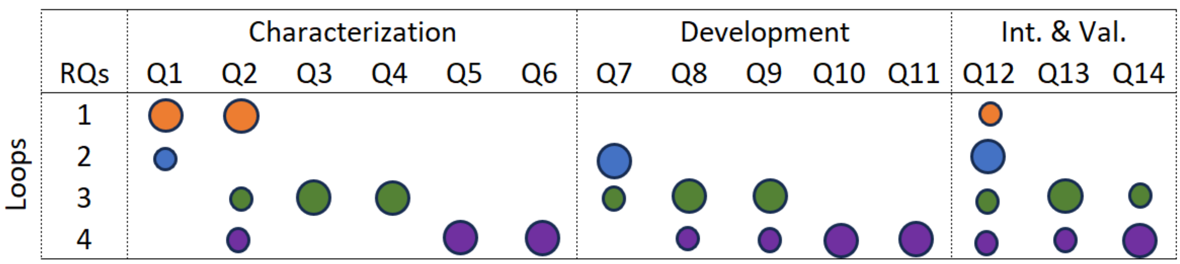

Figure 2. Example of SASER-based plan for case 2.

After they were done with arranging the research questions in loops using the SASER template (Figure 1), we used the last 10-15 minutes to reflect and discuss their choices and we made an integrated SASER picture with all their approaches drawn with different colored markers. Following the discussion, the participants filled post-its offering constructive feedback, remarks and considerations on the workshop, but more importantly on the application of SASER for organizing research in a spiral way (Figure 3).

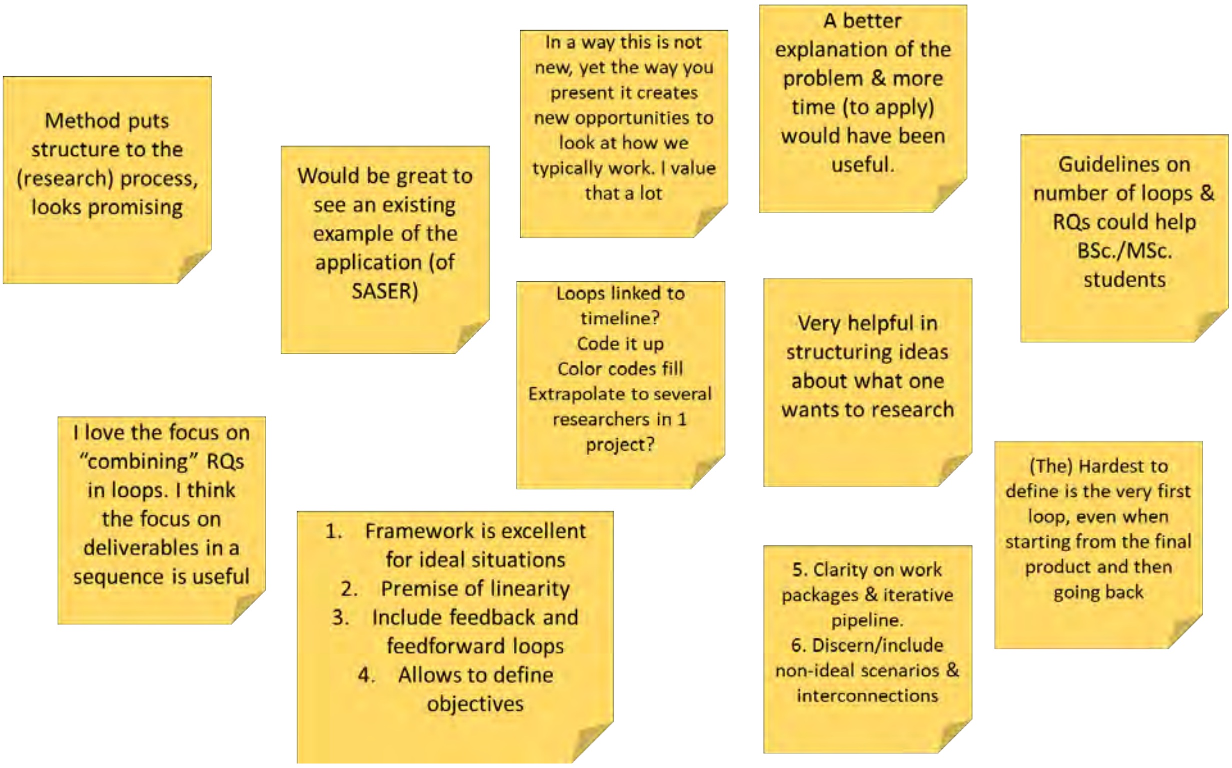

Figure 3. Received feedback.

5 CONCLUSIONS AND SIGNIFICANCE FOR ENGINEERING EDUCATION

The SASER approach targets academics, practitioners of education, and people working in the education or research collaboration between industry and academia. In the context of engineering research, the expected benefit is enhancing the educators' competence on supervising research and on defining a research methodology in the case of industry-based research. In the context of engineering education, the expected benefit is enhancing the educators' competence on creating a challenge solving dynamic, which enhances the mutual gains from the interaction between academia and industry. By increasing such competences, the educators can augment the supervised students' confidence, avoid being trapped into the analysis phase, guarantee that the work delivers value to industry, and strengthen the relationship with the industry partners.

The feedback received during the workshop (Figure 3) pointed that he main contribution from SASER are that it: (1) provides a structure and a process for organizing research with the industry involved; (2) has a clear, explicit focus on deliverables; and (3) offers clear feedback moments.

However, the comments also raise a few interesting points for improvement. So far we only applied SASER in Ph.D. projects within the SEMD research group at the University of Twente. So, indeed there is a need for adaptation of SASER to serve the research needs and circumstances of BSc. and MSc. assignments. The authors are currently researching the feasibility of SASER with master students. These cases are planned to be compiled as a library of examples of SASER applications, which is also in line with the feedback received by the workshop attendees. The authors also observed the difficulty of defining the very first loop, which could also be solved by having more examples.

What was however missing in this workshop (for practical reasons) was the presence of multiple stakeholders (academic and industrial). SASER is an output of constant communication between the different involved parties, in an effort to define a balanced and widely interesting research plan.

Lastly, there was the suggestion to make a software tool out of this process, so that multiple researchers are connected to the same SASER, and a timeline is provided. However, as we are still exploring the feasibility and usefulness of SASER we prefer revisiting this suggestion in the longer term.

ACKNOWLEDGMENTS

The authors would like to thank Prof. Maarten Bonnema, Usama Ahmed, and Jan Lenssen for co-developing part of the workshop materials. We would also like to thank our enthusiastic participants for their insights and feedback. Finally, this workshop was partially funded by the 4TU.CEE.

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Getting started – hands-on producing lecture films

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Conference Key Areas: *10. Virtual and Remote education in a post Covid world*
Keywords: *lecture films, peer-to-peer approach, undergraduate teaching, material science, mechanical engineering*

ABSTRACT

Lecture videos are more and more implemented in higher engineering education to be used widely by students because very often literature only presents results but not how to get there. Lecture videos may close this gap and visualize the sometimes obvious but still hard-to-understand scientific background. To attract students and become a fully accepted learning material these videos need to be of a certain standard. Based upon our 8 years of experience it is important is to involve students directly into the concept and making-of (peer-to-peer approach), because students` needs and their perspectives on teaching material are directly included in the videos. To encourage lecturers in engineering this workshop provides a short guidance to look at the peer-to-peer approach and more important basic needs and requirements of the lecture film production and "just get started". Good lecture videos may successfully be produced with low threshold.

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1 MOTIVATION

Lecture videos are an essential tool for future engineers because they provide an audio and visual stimulus that caters to different learning methodologies [1], and flexible and accessible way to learn and review complex engineering concepts. By recording and sharing lectures, professors can create a library of educational resources that can be accessed at any time, allowing students to review and reinforce their understanding of the subject matter. Additionally, lecture videos can help students who may have missed a class or need to catch up on missed content due to unforeseen circumstances. However, students tend to be overconfident in their learning from video-recorded modules [2]. But, with the increasing importance of online and distance learning or innovative teaching methods (e.g. inverted classroom method [3], [4]), lecture videos have become even more critical in providing quality education to future engineers.

2 BACKGROUND AND RATIONALE AND RELEVANCE

Very often literature only presents results but not how to get there, that is: calculations, models, atomic movement, solidification of alloys, phase transformations, etc.. Lecture videos may close this gap and visualize the underlying science behind the scene. Their purpose is to explain the sometimes obvious but still hard-to-understand scientific background.

To attract students and become a fully accepted learning material these videos need to be of a certain standard [5]. Based upon our 8 years of experience it is important is to involve students directly into the concept and making-of (peer-to-peer approach). The peer-to-peer approach directly influences the video project, the quality of the content and lecture video quality because students` needs and their perspectives on teaching material are directly included in the videos. Each semester, lecture videos are conducted during a term project, allowing for continuous improvement and adaptation based on feedback from the students. Effective operation of lecture films is based on students' experience and their specific needs when preparing for particular topics in material science. There are many different video techniques that will be introduced briefly. The following were successfully produced at HTW Berlin (Table 1): link to website https://www.werkstofftechnik.htw-berlin.

Table 1. Example lecture video techniques

Lecture film tecniques	***Rating***	***Acceptance***
Swipe technique	difficult	medium
Adding motion pictures	difficult	medium
Fast motion real time drawing,	easy to moderate	mecium
How to video	moderate	very high
Motion picture	easy	high
Screenplay	easy	high
including: power point animation	very difficult	medium
Handdrawing	difficult	medium
Stop-motion technique	difficult	high
Power-point animation	difficult	very high
Video scribe using hand drawn	moderate	very high

3 WORKSHOP DESIGN

This workshop focusses on different suitable video techniques, low threshold getting started, the script, challenges, getting students involved (peer-to-peer approach), implementation of lecture videos and the most important do´s and dont`ts. We did not focus on video equipment. A good overview on basic equipment is given in [6]. The workshop might create an exchange for further work with participants sharing own lecture films, useful OER, methods of evaluating the gain after implementing lecture videos or provide FAQ.

3.1 Target audience, participant knowledge required, target numbers of participants

The workshop mostly addresses "beginner", but also colleagues who want to discuss and exchange experiences. No prior knowledge is necessary. A good number of participants is 15, but even up to 30 is suitable because the hands-on work is done individually.

3.2 Motivation and Learning Outcomes

The motivation of this workshop comprises of:

1. Encouraging lecturers to start producing own lecture videos
2. Sharing experiences on workflow do`s and don`ts
3. Introducing the peer-to-peer approach and discuss how to involve students in the making-of
4. Demonstrating low threshold for video production applying KISS „keep it simple, stupid"
5. Enhancing students understanding and study motivation through different lecture video techniques.

Delegates of the workshop will know :

1. Different methods of implementing lecture videos

4 RESULTS OF THE WORKSHOP

Possibly due to the early morning hour and the special topic only 1 person was present in the beginning – later on 5 more showed up. Although the auditorium was small all collegues were very involved and motivated. We focussed on findings that have not been shared in any manual, publication or « how-to » of making videos and rebutted wrong thinking that lecture video production is very time consuming and of very high effort. The workshop was oraly evaluated highly helpful and beneficial by the participants with regard to the authors learning objectives and outcomes. Participants were introduced to and got involved in :

1. Getting started on the production of lecture videos
2. Basic video techniques and their technical needs
3. Necessary and unnecessary tools to get started
4. How to organize the workflow for conducting a lecture video
5. How to set up a script, time management and wording
6. Design of a lecture video and most important details

7. Hands-on: Setting up a short script (canvas was displayed (fig. 1) – because many questions aroused the writing was exchanged for a Q&A-session)
8. Implementation of lecture videos in inverted classroom teaching scenarios
9. Possible interactive lecture material based on the videos (e.g. H5P)
10. Hands-on: One-minute lecture film with smartphone „paper cut out animation“

The following marginal points are vital for lecture videos to support the individual learning progress ::

- The less is more – cut out on redundant details
- Highlight most important messages
- Personal style – creating individuality and connecting lecturer and learner
- Individual time set is possible – slow speaking voice over
- Interactivity – integrate quizzes within lecture video

Therefore, participants know that the multimedia principle combines words and picture simultaneously with regard to:

- Mulitmedia principle: Combining word and picture – especially for beginner students and new topics
- Coherence: Avoid intersting but redundant elements
- Signaling: Highlight most important aspects
- Contiguity: Alignment of voice-over and visualization, local neighbouring
- Redundancy: Picture and voice-over: yes – picture, voice-over and text: no (Fig. 1)

Fig. 1. One of the most important lecture video design aspect: avoid redundancy

The following hands-on activities were introduced but because of ongoing questions and lively discusion have not been conducted by the participants during the workshop :

4.1 Hands-on activities

Setting up a short script :

Delegates will chose their own project to work on according to the learning video canvas (Fig. 2). After reflecting on target group, learning goal and ideas for implementation delegates explain a topic within their field in only 5 sentences.

Fig. 2. Concept map to set up a lecture video. The template can be retrieved from: https://zenodo.org/record/4624701#.Y1QWcEzP2wc or https://sansch.wordpress.com/2021/04/21/published-the-learning-video-canvas/

One-minute lecture film with smartphone „paper cut out animation“

The delegates are shown how conduct a 1 minute lecture paper cut out animation lecture video on their topic chosen using paper, pen, smartphone a tall glass and tape (Fig. 3). Depending on the time everyone is encouraged to produce their own short lecture video. This can also be part of a lecture with students.

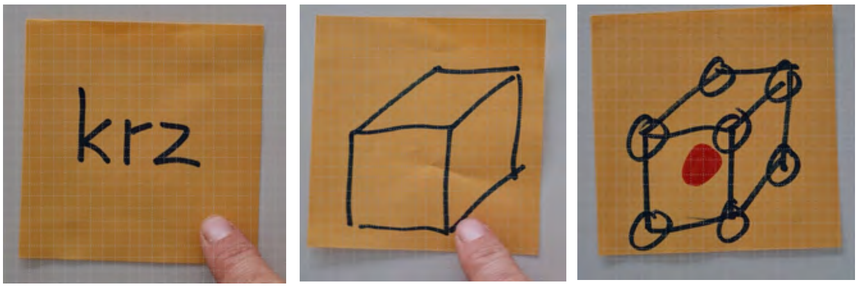

Fig. 3. Examples of a low threshold lecture video paper cut out animation

5 SIGNIFICANCE FOR ENGINEERING EDUCATION

In engineering education visualization is necessary and supportive for students when the underlying science remains imaginary such as physics, chemistry and especially material science. Because lecture videos do not have to be technically perfect to be accepted as full teaching material by students the findings that have not been shared in any manual, publication or « how-to » of making videos are of special value such as : lecture video production being very time consuming and of very high effort. There are good and easy ways to visualize content without becoming a future film editor.

Most important findings for engineering educators are that the skript has to be matched to the assets and wording has to be aligned exactly to the visualization. A maximum of 6-9 minutes is recommended referring to students ability to concentrate on digital (difficult) content.

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Using Technology to Teach/Learn Mathematics, How Are we as Teachers Fostering Mathematics Education Mobility?

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Conference Key Areas: *Innovative Teaching and Learning Methods*
Keywords: *Pedagogical strategies, ICT usage, Mathematics*

ABSTRACT

Mathematics education plays a critical role in developing analytical thinking, problem-solving skills, and logical reasoning abilities among students. With the rapid advancements in technology, the integration of Information and Communication Technology (ICT) has opened new possibilities for teaching and learning mathematics. In the field of engineering education, the use of ICT tools and methodologies has gained significant attention due to their potential to enhance mathematical understanding and application within an engineering context.
Traditionally, mathematics was taught using traditional pedagogical methods such as lectures, textbooks, and pen-and-paper exercises. However, the integration of ICT tools significantly enhanced the teaching and learning experience. Interactive simulations, computer algebra systems, graphing calculators, educational software, and online resources offer dynamic and engaging platforms for exploring mathematical concepts.
In Engineering Education, the integration of ICT tools in mathematics instruction has become increasingly prevalent. Engineering-specific software packages, computational tools, and programming languages provide students with practical applications of mathematics in engineering contexts. The use of virtual laboratories, simulation software, and data analysis tools helps students connect mathematical concepts to real-world engineering problems.
It seems widely accepted that integration of ICT in mathematics education, particularly in the field of engineering education, has transformed traditional teaching and learning approaches. By leveraging the power of technology, educators can enhance students' understanding, engagement, and application of mathematics. As technology continues to advance, embracing ICT integration in mathematics education becomes imperative to prepare students for the challenges and opportunities of the engineering profession.
In this paper we will present the results of a questionnaire, answered by 29 teachers from 16 countries at the SEFI'2023 conference. This questionnaire delved into teachers' perspectives on utilizing ICT tools and different pedagogical strategies for teaching mathematics.

1 MOTIVATION AND LEARNING OUTCOMES

With this workshop authors intended to do a survey of the software, platforms, ICT approaches that are used by the attendees and the achievements in terms of consolidated knowledge.
Attendees were invited to answer some specific questions regarding ICT platforms and software possible to use while teaching and/or learning Mathematics and perform an evaluation of how their perception of the knowledge is acquired by their students.
After collecting the above information, a discussion/reflection period between the attendees was promoted in order to generate conclusions that are fruitful and may be

accomplished by Mathematics teachers when returning to their universities. A not necessarily equal but similar way of teaching and learning Mathematics across Europe is crucial for fostering educational mobility and enhancing students' mathematical competence. By aligning pedagogical methods, curricula, and learning outcomes, students can benefit from a harmonized educational experience that transcends borders. Collaboration, consistent academic standards, and a strengthened European identity are the fruits of such endeavours. Embracing this shared vision of Mathematics education will prepare students to tackle the challenges of a globalized world and contribute to the development of a highly skilled and interconnected workforce.
The following bullet points summarize the content of the workshop and its design:

- A 10-minute activity showing the most common ICT tools used by Mathematics teachers
- A 10-minute activity of individual reflection and questionnaire answers
- A 30-minute discussion/reflection among all attendees
- A 10-minute wrap-up and conclusions document construction to take away.

2 BACKGROUND RATIONALE AND RELEVANCE

Mathematics education plays a critical role in developing analytical thinking, problem-solving skills, and logical reasoning abilities among students. With the rapid advancements in technology, the integration of Information and Communication Technology (ICT) has opened up new possibilities for teaching and learning mathematics. In the field of engineering education, the use of ICT tools and methodologies has gained significant attention due to their potential to enhance mathematical understanding and application within an engineering context. This workshop delves into the state of the art in teaching mathematics, emphasizing the integration of ICT tools and techniques in engineering education and their evaluation by the workshop attendees.
Mathematics serves as a foundation for various disciplines, including engineering. It develops logical thinking, quantitative reasoning, and problem-solving abilities. A solid mathematical background is crucial for students to succeed in their engineering education and future careers.
Traditionally, mathematics was taught using traditional pedagogical methods such as lectures, textbooks, and pen-and-paper exercises. However, the integration of ICT tools significantly enhanced the teaching and learning experience. Interactive simulations, computer algebra systems, graphing calculators, educational software, and online resources offer dynamic and engaging platforms for exploring mathematical concepts. By integrating ICT in Mathematics Education several benefits may be accomplished, such as
1. Visualization and Conceptual Understanding: ICT tools facilitate the visualization of complex mathematical concepts, enabling students to develop a deeper understanding of abstract ideas. Dynamic visual representations and simulations help students grasp mathematical relationships and patterns more effectively.
2. Active Learning and Engagement: ICT tools promote active learning by providing interactive platforms for students to actively engage with mathematical problems. Students can explore mathematical concepts through hands-on activities, simulations, and multimedia resources, fostering a deeper level of engagement and motivation.

3. Personalized Learning and Differentiation: ICT allows for personalized learning experiences tailored to individual student needs. Adaptive software and online platforms can provide targeted instruction, immediate feedback, and adaptive challenges, catering to students' unique learning styles and paces.
4. Collaborative Learning: ICT tools enable collaborative learning experiences, facilitating communication and collaboration among students. Virtual platforms and online forums create opportunities for students to discuss, solve problems, and share mathematical insights, fostering a collaborative and supportive learning environment.
In Engineering Education, the integration of ICT tools in mathematics instruction has become increasingly prevalent. Engineering-specific software packages, computational tools, and programming languages provide students with practical applications of mathematics in engineering contexts. The use of virtual laboratories, simulation software, and data analysis tools helps students connect mathematical concepts to real-world engineering problems.

3 RESULTS AND CONCLUSIONS

Twenty nine individuals from 16 different countries, Fig. 1, were present at the workshop and answered the proposed questionnaire.

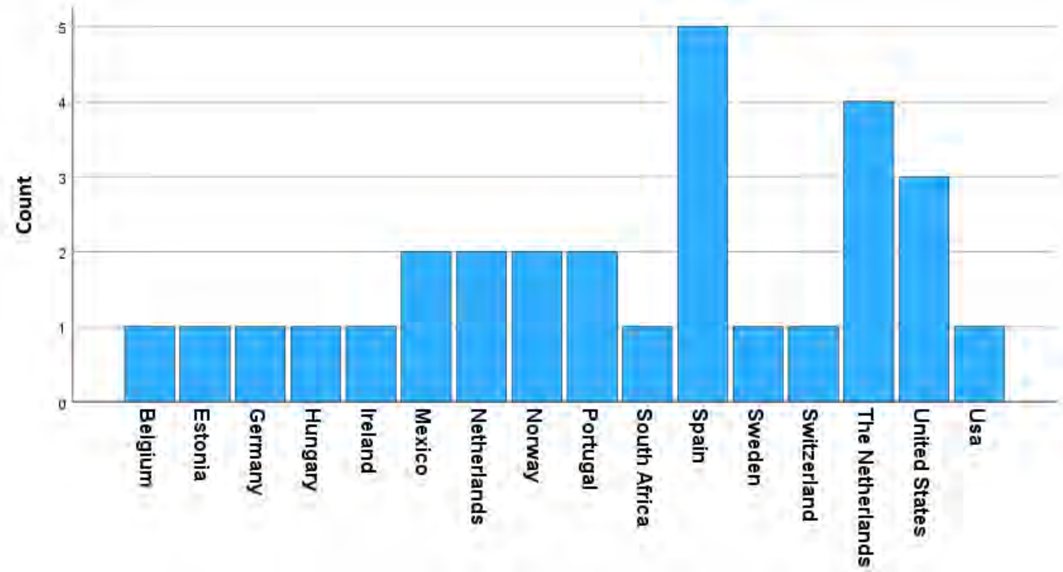

Fig. 1. Attendees origin country

The gender distribution was balanced between male and female individuals, as shown at the pie chart below, which allows to analise possible different perspectives

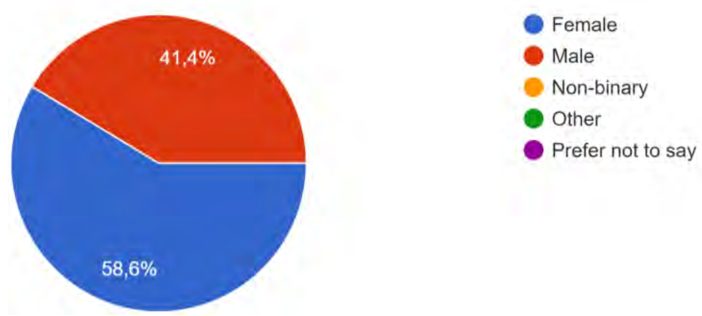

Fig. 2. Attendees gender

The years of teaching experience among workshop attendees were also considered an important variable that could potentially influence the subjects being discussed. As evident from the histogram, Fig. 3, representing attendees' years of teaching experience, the sample includes individuals from all experience levels.

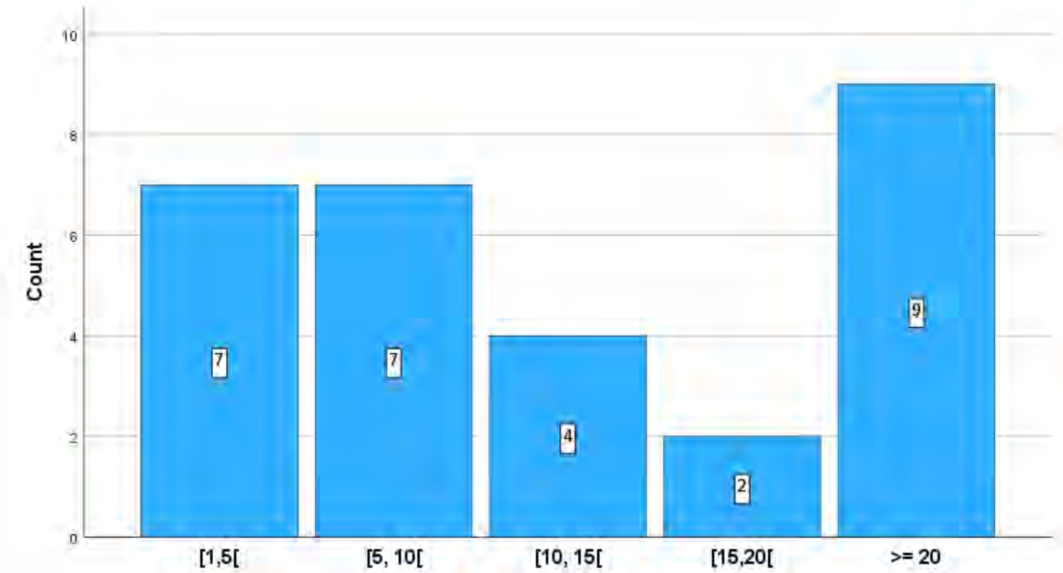

Fig. 3. Attendees teaching experience years

From a list of possible Mathematics curricular units, which may have different strategic pedagogical approaches, attendees were asked to choose which ones did they teach. At Fig. 4 we may observe their answersy

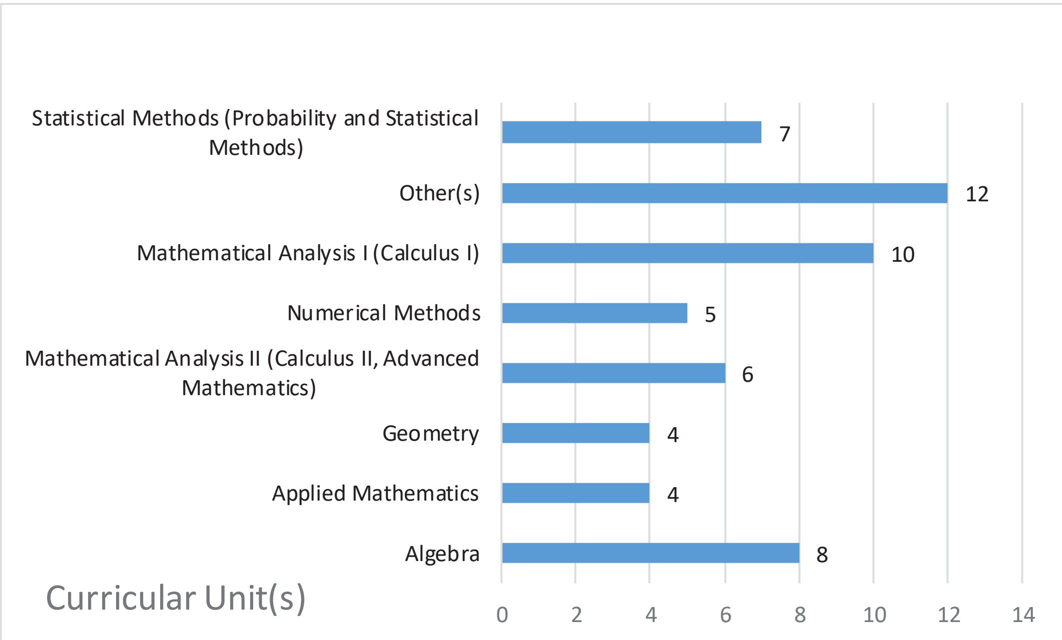

Fig. 4. Attendees curricular units taught

Regarding different pedagogical strategies, Fig. 5, we observed that all attendees use at least one pedagogical strategy besides standard education model (expository using only blackboard).

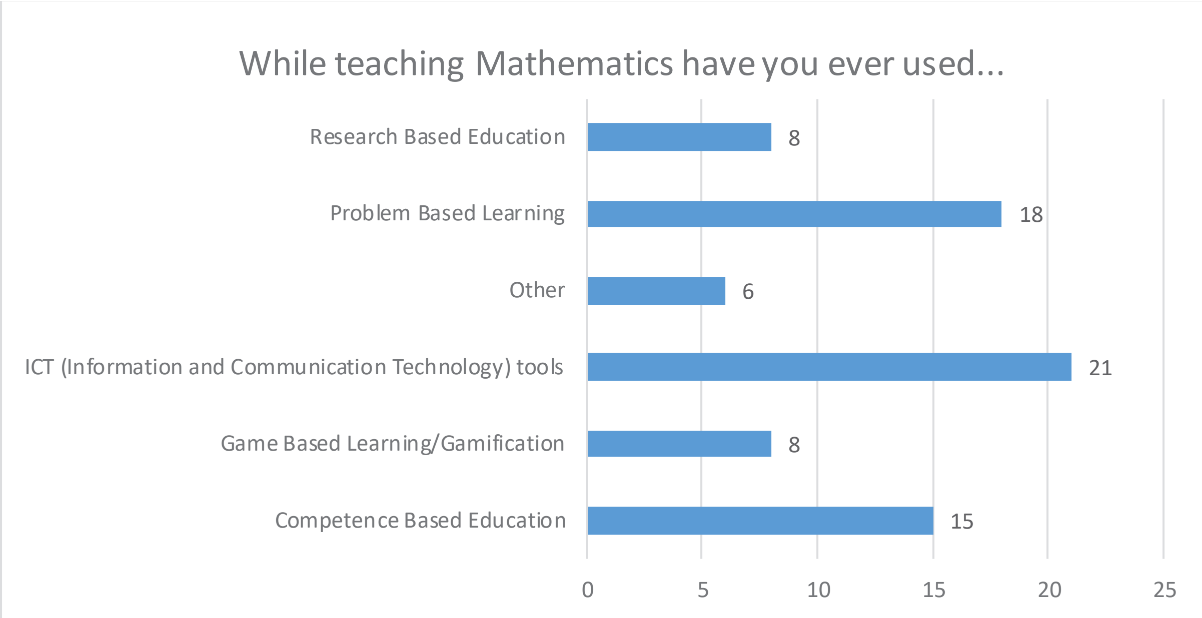

Fig. 5. Attendees pedagogical strategies

When asked about the frequency with which the above mentioned pedagogical methods were applied, we may observe, Fig. 6, that their applicability are at nearly half the amount of classes taught within a semester.

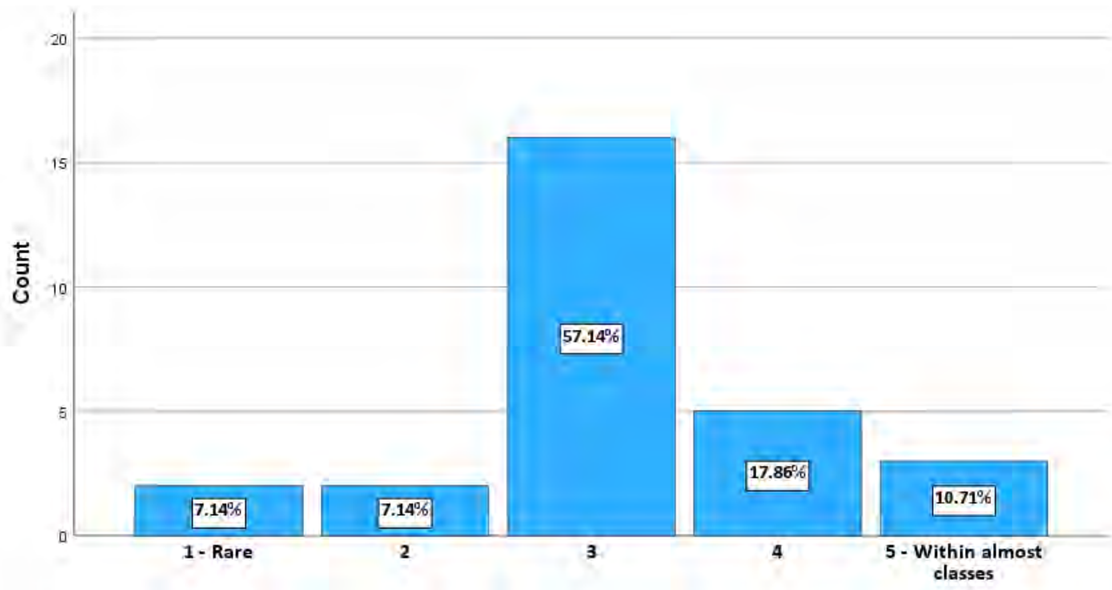

Fig. 6. Attendees different pedagogical strategies usage

When trying to apply these strategies difficulties arise and the pointed main ones that attendees face when overcoming traditional pencil and paper Mathemaics classes were, Fig. 7,

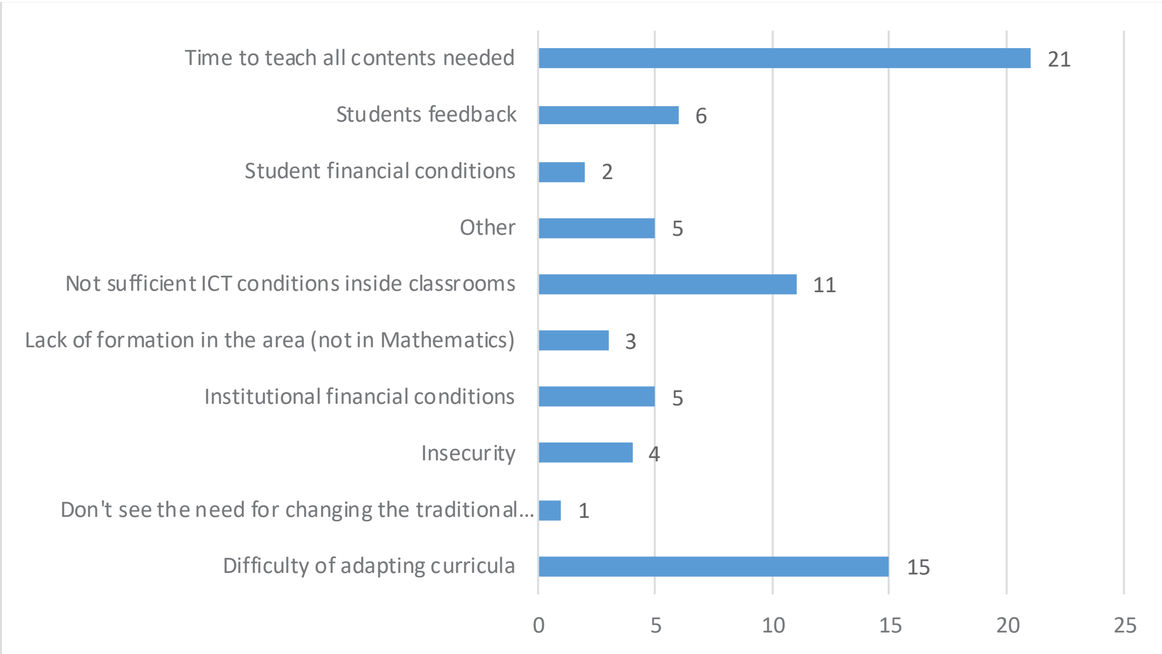

Fig. 7. Attendees main diffilcuties regarding the applicability of different strategies

It's worth noting that the major challenges lie in the time required to teach all necessary content and adapt the curriculum. In future endeavors, fostering synergies between those responsible for engineering curriculum development and mathematics teachers should be regarded as a crucial theme.

The purpose of ICT tools usage inside classes are, for the present attendees, Fig. 8,

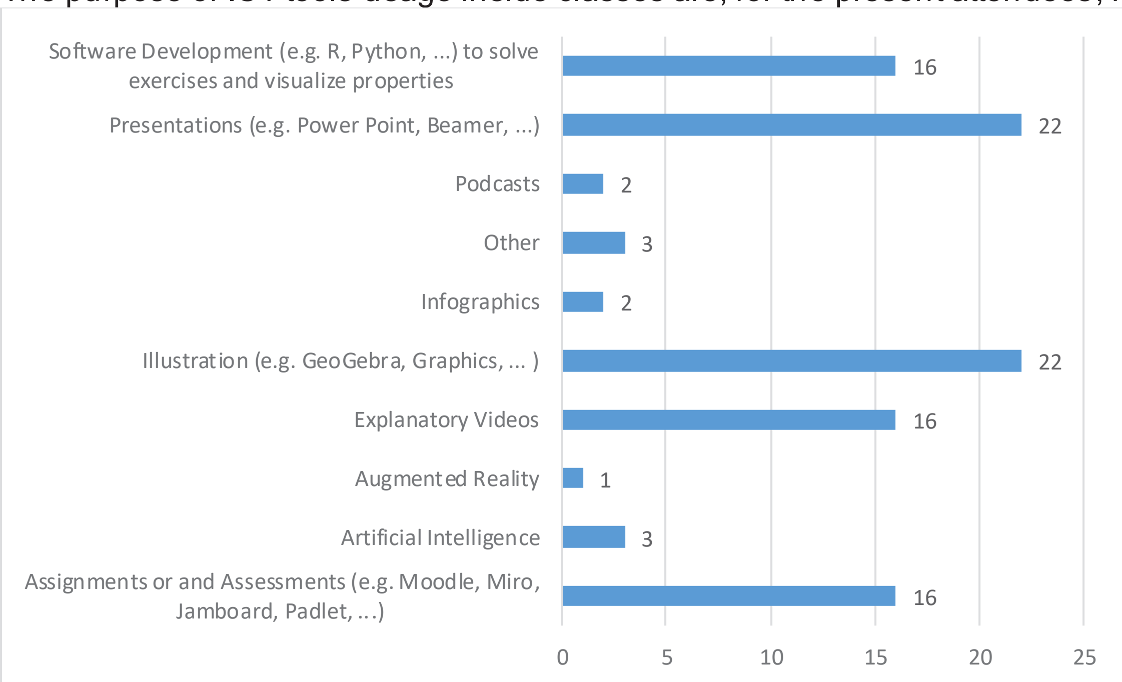

Fig. 8. Attendees ICT tools usage purpose

Students feedback regarding the use of ICT tools is encouraging as expected

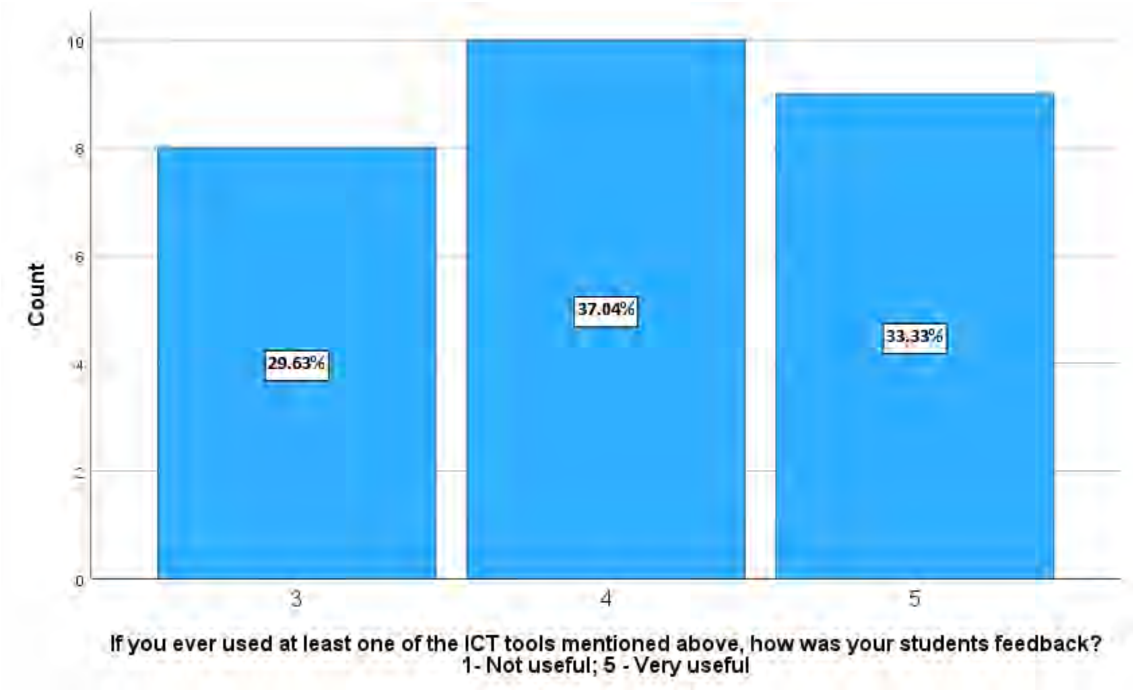

Fig. 9. Attendees students feedback

At the conclusion of the semester, attendees' perception of students' apprehending mathematical concepts is moderate. This suggests that nearly all students grasp the concepts to some extent, although they may not achieve expertise. However, the concepts can be considered as having been apprehended by the students.

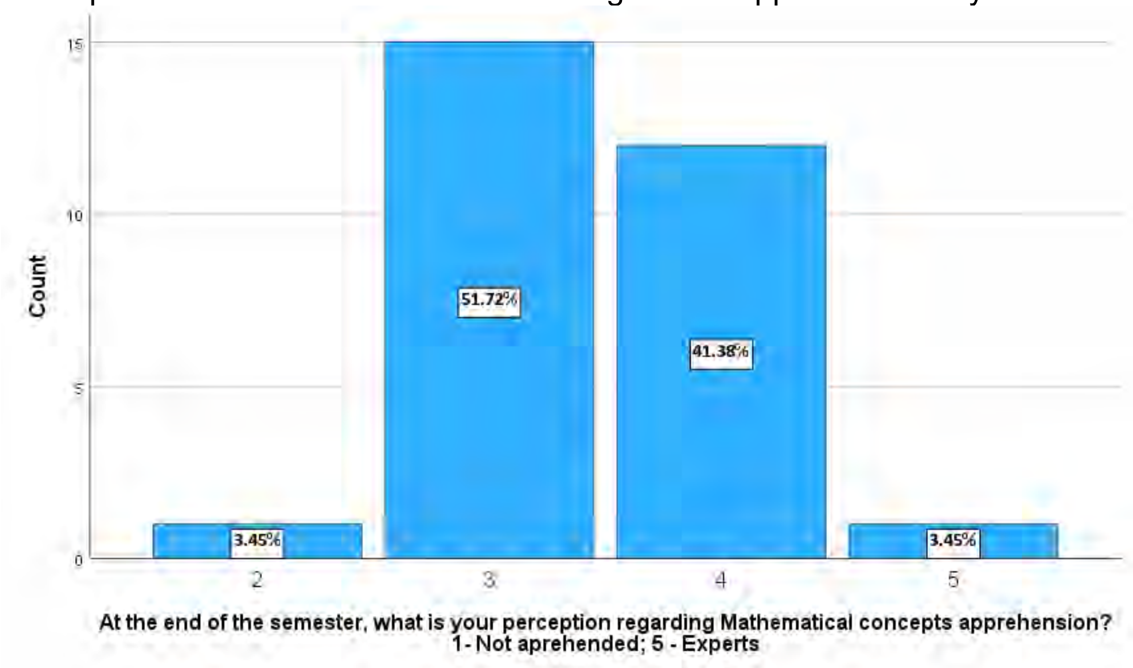

Fig. 10. Attendees' students concepts aprehension

Nevertheless, apprehending the concepts is not a synonym of rigorous application and the attendees' perception regarding the rigour with which the Mathematical concepts were grasped reflects it, Fig. 11,

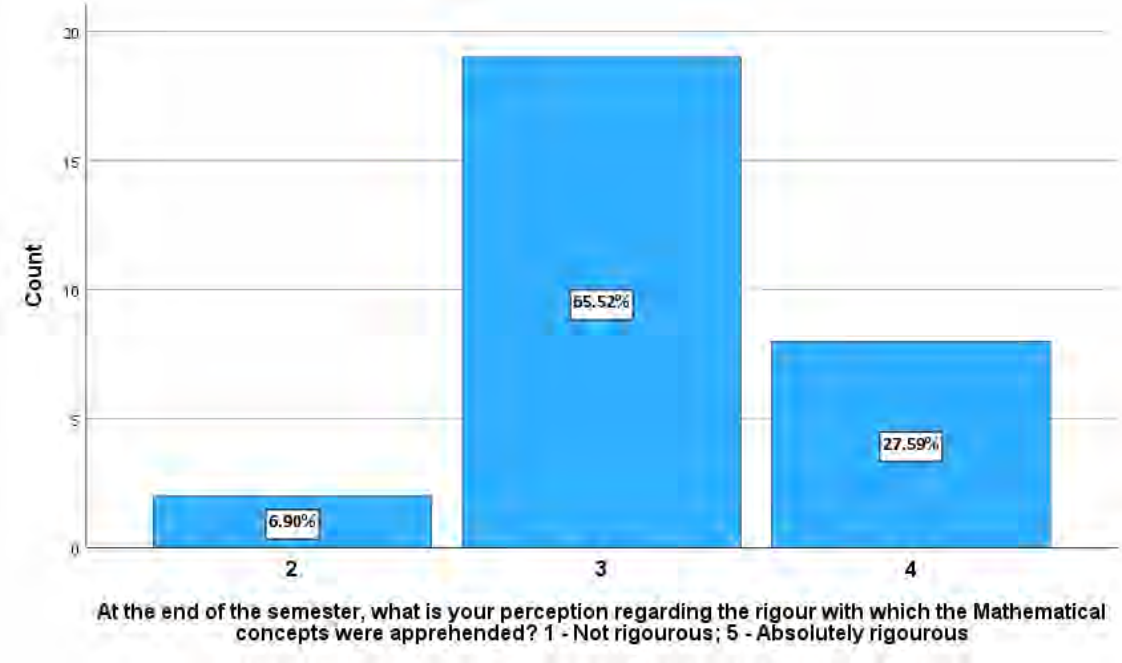

Fig. 11. Attendees' students concepts rigour

Authors were also interested in understanding which Mathematical competences were most valued by the attendees. The answer to that question reveals that to the attendees present at this workshop the most valued competences are the ability to be critical about the solution obtained and also the ability to apply the acquired knowledge to a different situation as we may observe on Fig. 12 a) b)

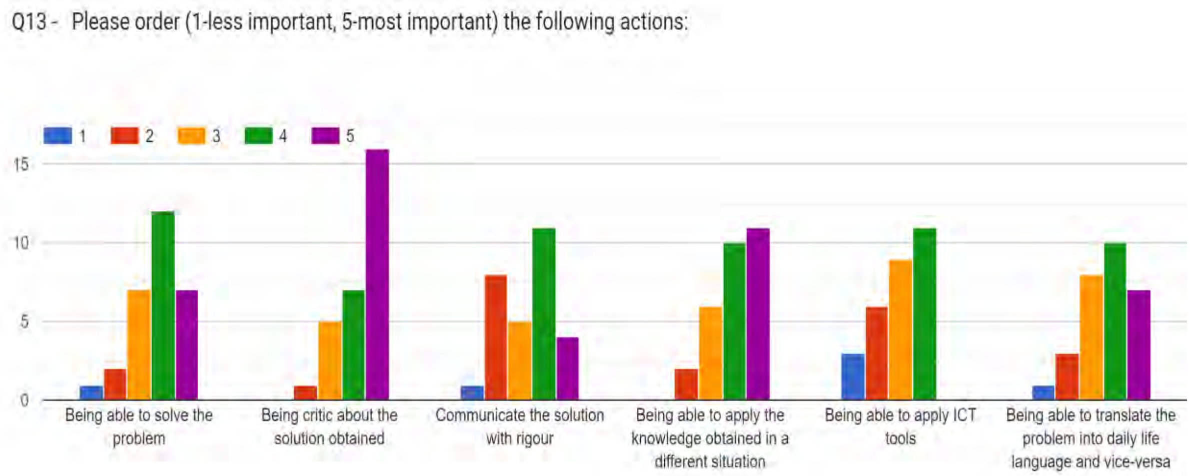

Fig. 12 a). Attendees competences ordering

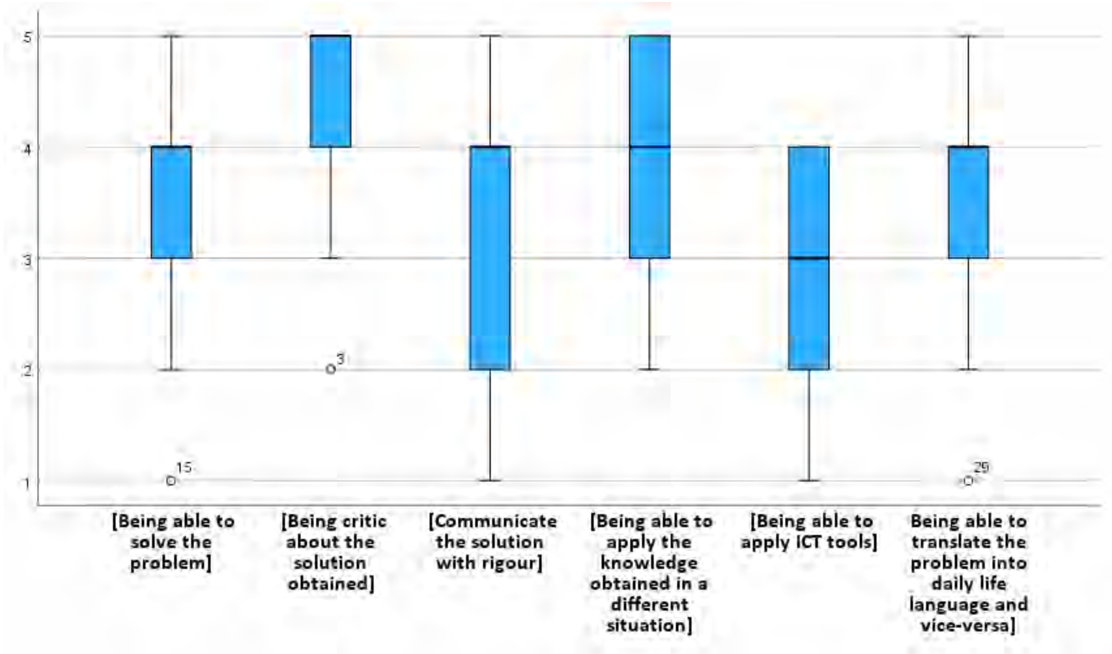

Fig. 12 b). Attendees competences ordering box-plot comparison

At the end of the questionnaire authors asked attendees to share some fruitful educational experience in terms of: pedagogy, ICT tools used, assessment procedures, etc., and the inputs received were the following:

- Challenge-Based learning, Using Möbius to provide feedback and test;
- ICT tools: use Mathematica for numerical methods;
- 3blue1brown makes very good infographics. Fliped classroom works well if the videos are short covering only one subject and can be speed up;
- Using Padlet in laboratory classes;
- Integration Competition;
- Vevox for class engagement, Brightspace for notes and assignment uploads. Regular communication;
- Integration with engineering design, science and mathematics for an authentic problem or product;
- Escape room for review, mind map with the different topics;
- Workshops with students using challenges and experiments as a way to foster thinking and stimulate interest demonstrating that science (stem) can be funny;
- Using Geogebra for dynamic illustration is simple and worthwhile;
- Individually collected data analysis team-project in Statistics course;
- My students have been using Jupyter notebooks for image processing, where concepts of linear algebra are treated;
- Creating/updating activities/tasks that were used for in person teaching to a virtual teaching could be one aspect that we should focus in using Technology in Mathematics education;
- Discussing language models and how they relate to conditional probability, and having students start googling searches and discuss why Google proposes different next words for us;

- Not mine but simple and still beautiful work of some colleagues: "Algorithmic Battle". Students team up against each other developing algorithms for hard combinatorial problems and instance generators to generate tricky instances;
- Peer assessment;
- Students don't mind being prompted with questions as long as grade not affected;
- Service Learning;
- Geogebra can be incredibly useful for students to use themselves to visualise. For example (this is high school level) when learning about the unit circle and sinus and cosines as functions, applets in Geogebra can be a huge addition;
- I teach a combined ordinary differential equations and linear algebra course for engineering students. Through collaboration with the engineering department, we created an integrated lab component to the course involving a mix of numerical methods and experimental data. As an example, we use a beam deflection lab to have students measure the system's Green function;
- The use of Polya's 4 step method to encourage students to be critical of their own answers or those of others proved to work really well for me in a high school context;

4 SIGNIFICANCE FOR EDUCATION

It seems widely accepted that integration of ICT in mathematics education, particularly in the field of engineering education, has transformed traditional teaching and learning approaches. By leveraging the power of technology, educators can enhance students' understanding, engagement, and application of mathematics. As technology continues to advance, embracing ICT integration in mathematics education becomes imperative to prepare students for the challenges and opportunities of the engineering profession.
In an increasingly interconnected world, fostering education mobility has become essential for preparing students to thrive in a globalized society. Within the realm of mathematics education, promoting not necessarily equal but similar teaching and learning approaches across Europe holds great importance. Harmonizing mathematical education methods and fostering mobility among students, emphasizing the advantages of a shared pedagogical framework in promoting educational excellence and enhancing students' mathematical competence is a preoccupation of some teachers. Europe is a diverse continent with a multitude of educational systems and approaches to teaching mathematics. While each country has its unique cultural and educational context, fostering a more similar framework of mathematics education can bridge the divide between different systems. This ensures that students, regardless of their geographic location, have access to high-quality mathematics education and can seamlessly transition between educational systems. Promoting a similar approach to teaching and learning mathematics across Europe facilitates educational mobility for students. When mathematical concepts and pedagogical methods align, students can transfer their knowledge and skills more easily when moving between countries or participating in international exchange programs. This mobility opens doors for students to experience different educational systems, gain diverse perspectives, and develop adaptability skills. A shared understanding and implementation of mathematics education methods can contribute to the establishment of consistent academic standards across Europe. By aligning curricula,

learning outcomes, and assessment practices, educational institutions can ensure that students receive a comparable level of mathematical education, regardless of their location. This consistency fosters transparency and helps students and employers recognize and evaluate mathematical competence uniformly.
Promoting similar teaching and learning approaches in mathematics encourages collaboration and knowledge exchange among educators across Europe. When educators share best practices, pedagogical strategies, and innovative approaches to teaching mathematics, it enriches the professional development of teachers and contributes to the continuous improvement of mathematics education. This collaboration can occur through teacher training programs, conferences, online platforms, and professional networks. By embracing a shared pedagogical framework, Europe can foster a sense of unity and belonging among its diverse nations. This shared educational experience helps create a cohesive community, where students can learn from one another, appreciate cultural diversity, and develop a deeper understanding of their European counterparts.

5 ACKNOWLEDGMENTS

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PLANNING INTERDISCIPLINARY ARTIFICIAL INTELLIGENCE COURSES

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***Conference Key Areas**: Education about and with Artificial Intelligence*
***Keywords**: Interdisciplinary Competences, Engineering Skills and Competences, Course Planning, AI Literacy*

ABSTRACT

As Artificial Intelligence (AI) becomes increasingly important in engineering, instructors need to incorporate AI concepts into their subject-specific courses. However, many teachers may lack the expertise to do so effectively or don't know where to start. To address this challenge, we have developed the AI Course Design Planning Framework to help instructors structure their teaching of domain-specific AI skills. This workshop aimed to equip participants with an understanding of the framework and its application to their courses. The workshop was designed for instructors in engineering education who are interested in interdisciplinary teaching and teaching about AI in the context of their domain. Throughout the workshop, participants worked hands-on in groups with the framework, applied it to their intended courses and reflected on the use. The workshop revealed challenges in defining domain-specific AI use cases and assessing learners' skills and instructors' competencies. At the same time, participants found the framework effective in early course development. Overall, the results of the workshop highlight the need for AI integration in engineering education and equipping educators with effective tools and training. It is clear that further efforts are needed to fully embrace AI in engineering education.

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1 MOTIVATION AND LEARNING OUTCOMES

Tools and methods of Artificial Intelligence (AI) are becoming more and more important in the engineering practice. This also requires instructors to integrate AI as content in their domain-specific courses. In this context, AI education often goes beyond basic AI competencies and capabilities (often referred to as AI literacy). It also goes beyond what can be framed as consumer AI, for example currently in hype generative large language models, and focuses on industrial AI. Rather, students should learn how to work with and apply industrial AI in their specific subject or even develop domain-specific solutions themselves (Schleiss et al. 2022a). However, this presents a challenge for teachers who may not be computer scientists themselves, and who may not have expertise in AI. To address this problem, we have developed the *AI Course Design Planning Framework* (Schleiss et al. 2023) to help instructors structure and design their teaching of subject-specific AI skills.

This workshop aims to promote the ability of instructors to teach domain-specific AI skills in a structured and effective manner. After the workshop participants can:

- distinguish between AI literacy and more advanced AI competencies
- understand important categories and leading questions for developing domain-specific AI courses using the framework
- apply the AI Course Design Planning Framework for their own course and discipline context

2 TEACHING ABOUT ARTIFICIAL INTELLIGENCE IN ENGINEERING EDUCATION

Interdisciplinarity gains relevance in engineering education (Van den Beemt et al. 2020). This also includes bridging the gap between disciplines and integrating methods from other fields in the teaching offers. In this context, education about AI is domain-specific, and means teaching AI as a method in a certain domain context. An example can be the use of AI methods for sustainability in terms of process improvements or energy optimization (Van Wynsberghe 2021).

This interdisciplinary approach to AI education aims to resemble real-world problem-solving and motivate students through relevance (Lindvig and Ulriksen 2019; Janssen et al. 2020). At the same time, domain-specific AI education requires a good understanding of the background, and prior experiences of students (Ng et al. 2022). Moreover, instructors themselves often combine their domain expertise with the topic of AI, which requires self-reflection on their own competencies and role in the learning process (Kim et al. 2021; Ng et al. 2023).

Some examples of teaching AI in an engineering education context have tested a practice-based learning approach using a combination of projects and OER (Schleiss et al. 2022b) or a modular approach for learning paths that involve different depth and content depending on the target group in an industry setting (Salazar-Gomez et al. 2022). With the rapid development of AI technology, it is apparent that there is a need for a structured approach to AI course development at the intersection of AI and the engineering domain that allows educators to reflect their current courses with their respective learning outcomes, assessments and activities, and assess if they want to integrate new perspectives based on the development and use cases around AI in their domain context.

3 WORKSHOP DESIGN

The workshop was organized as an interactive session in which participants were invited to actively contribute their experiences and insights in all the workshop segments. Moreover, throughout the workshop, participants applied the AI course design planning framework (see Figure 1) to their intended courses and reflected in small groups on its potential strengths and weaknesses.

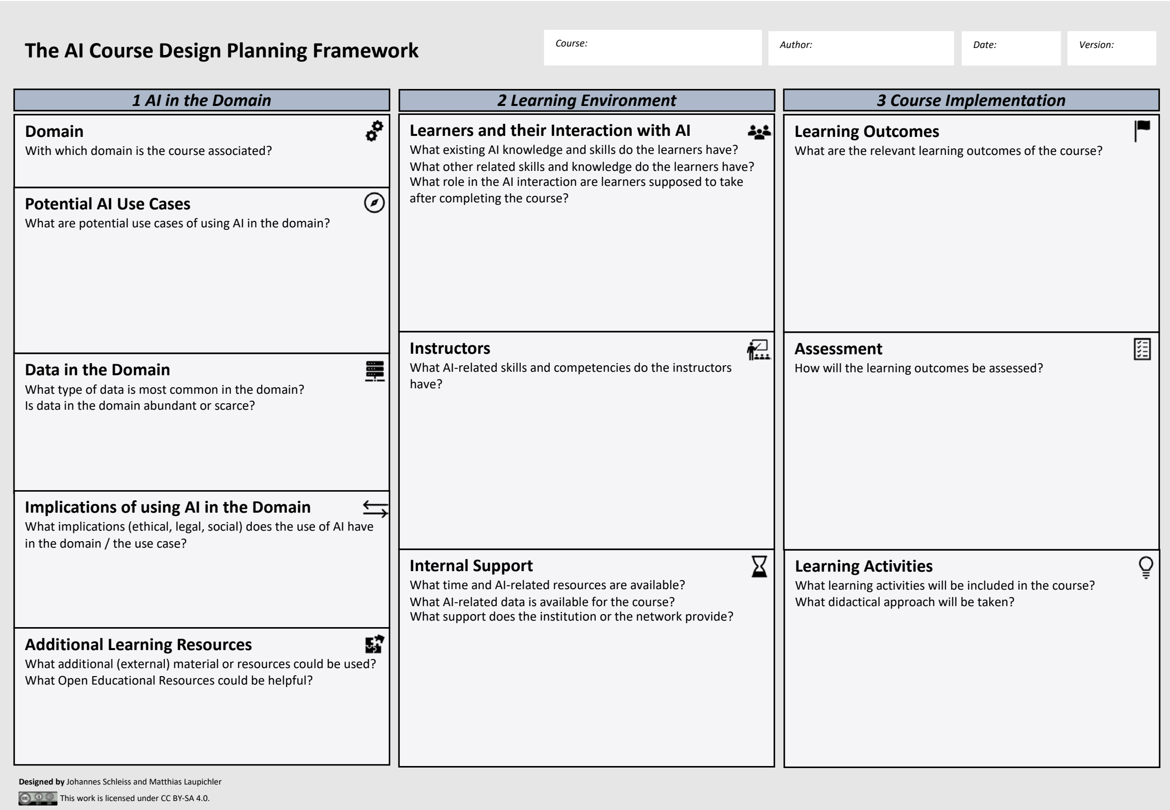

Fig. 1. The AI Course Design Planning Framework (Source: Schleiss et al. 2023). A blank version is also available via https://education4ai.github.io/ai-course-design-planning-framework/ (Accessed 21.09.2023).

Workshop Structure

The workshop was structured as follows:

- **Introduction:** Interactive presentation to AI competencies and the AI Course Design Planning Framework (15 minutes)
- **Group Work:** Developing courses with the AI Course Design Planning Framework in a collaborative group activity with groups of 3-5 people (30 minutes)
- **Reflection:** Sharing outcomes of the group activity and evaluating the use of the AI Course Design Planning Framework as a development framework and working out possible improvements (10 minutes)
- **Conclusion:** Collective summary of experiences in the group activity (5 minutes)

Target Audience

The workshop was designed for instructors in engineering education who are interested in interdisciplinary teaching and teaching about AI in the context of their domain. A basic understanding of AI was sufficient to attend the workshop. At the same time, the workshop did not dive deep into explaining AI technology but will focus on the competencies and considerations that need to be taken when planning an AI course.

4 RESULTS OF THE WORKSHOP

In the workshop, the 35 participants split into six groups and used the AI Course Design Planning Framework for an exemplary chosen course. While the time given to work with the framework allows a first start, it is usually not enough to complete filling it out within a limited timeframe of 30 minutes. In working with the framework, the following observations, experiences and difficulties were identified.

First, multiple groups had difficulties in defining potential AI use cases in the context of their domain, which some grounded in a lack of knowledge and skills in industrial AI from an educator perspective. This was also supported by the observation, that four out of six teams used use cases involving large language models, which could be categorized more as consumer AI. Some participants highlighted that they would have found it helpful to build upon existing use cases and examples.

Second, scoping the learners' skills and backgrounds was perceived as difficult, especially considering the AI perspective. It was mostly unclear for educators how much students use, for example, consumer AI and what can be drawn from these insights. Accordingly, there were not always insights into the competencies of instructors, especially in bigger course settings with multiple instructors.

Last, one group discussed the category of implications of using AI in the domain and mentioned that the environmental implication could be an addition.

Overall, participants highlighted the simplicity of the framework and that it allows for quick iteration in course development, especially in earlier development phases. They also found it easy to work with the right part of the canvas, which corresponds to classical course planning frameworks.

Multiple people indicated their interest in the materials and to potentially participate in follow-up research studies.

5 CONCLUSIONS

With the rapid advancement of the field of AI, it becomes more and more important to integrate teaching about AI in the respective curricula and courses. The primary objective of the workshop was to support instructors in familiarizing themselves with possible AI competencies in their respective domains and to provide them with the tools to develop domain-specific AI courses.

The outcomes of the workshop underscored the efficacy of the AI Course Design Planning Framework as a valuable and user-friendly resource for course development and discussion. At the same time, it was apparent that there was a lack of knowledge in industrial AI that hindered the participants to fully embrace and utilize the framework.

These findings underscore the critical necessity for enhancing educators' competencies in AI. This also extends beyond merely addressing consumer-oriented AI applications within their teaching to the integration of relevant industrial AI use cases into the learning outcomes (Schleiss et al. 2023). In addition to providing comprehensive teacher training, the creation of a database featuring examples of existing courses could catalyze further development in this field. Furthermore, the aspect of (self-) assessment of AI competencies of students and teachers is a topic of need, similar to proposed in (Laupichler et al. 2023).

This workshop increased awareness and built a foundation for advancing the integration of AI topics and competencies into engineering education. At the same time, it also made clear that there is still some work to be done to fully embrace AI in engineering education.

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HOW CAN CONTINUING ENGINEERING EDUCATION APPROACHES MEET SOCIETAL AND INDUSTRY NEEDS FOR FUTURE-FOCUSED, LIFELONG LEARNING SKILLS AND COMPETENCES?

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***Conference Key Areas**: Continuing engineering education (CEE); CEE approaches; futures skills; future competences; lifelong learning;*

ABSTRACT

In this workshop run by the Continuing Engineering Education and Lifelong Learning SIG, attendees were first given an overview of the changing skills landscape from 2011 to 2023 to set highlight some of the international recognised priorities around skills. Next, the workshop attendees then examined in separate groups three questions around what and how Continuing Engineering Education (CEE) is being approached within different institutions. Shared experiences show that there are a variety of approaches (short courses and microcredentials) that were targeted at relevant local industries, and/or responding to a specific skills need. It was apparent that strategic direction is required from senior leaders within academic institutions to ensure appropriate resourcing is put in place to enable these CEE offerings. Also, more evidence is required around the desire and specific demand from employers to up-skill their employees, particularly in transversal skills. Opportunities were seen in micro-credentials and in coordinated approaches between education providers, industry and third-sector organisations. Various existing and potential models for CEE were discussed, including stackable and modular provision; use of personal coaches, MOOCs and microcredentials; the use of company-based academics; clusters of companies coming together to provide scale; and the role and use of Recognition of Prior Learning. Additionally, it is apparent that a responsive, agile and

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flexible system is required, so again requiring strategic direction. The discussions will feed into the SIG activities for the coming year.

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1 MOTIVATION

The focus on lifelong learning and Continuing Engineering Education (CEE) has gained new impetus in a post-COVID world (Ossiannilsson 2022). Additionally responding to rapid technological changes, and where new competences are required to address the “wicked” problems of the next decade, such as UN Sustainable Development Goals, will require education and re-education (UNESCO 2021). Moreover, previous forms of CEE, such as postgraduate taught qualifications, are not necessarily responsive enough to the needs of all individuals, organisations and society. Consequently, new forms of learning, such as micro-credentials, credit-rating, industry training programmes and certification, and flexible programmes, are emerging.

In this European Year of Skills, it was important that different stakeholders (academia, university, lifelong learners) came together to share how they are approaching meeting these challenges, how this CEE ecosystems are developing, and how we can work together to develop models that respond effectively to these needs and opportunities.

2 BACKGROUND AND RATIONALE AND RELEVANCE

The Continuing Engineering Education eco-system is complex, due to the different range of stakeholders involved – governments, professional bodies, trade unions, companies, engineers, as well as education and training providers – as well as the plethora of types of learning (informal, non-formal and formal) and the ways that these types of learning can be undertaken (such as in-person, on-line, credit-bearing).

Recent developments, such as micro-credentials, are seeing pan-European approaches being adopted (EU 2022), including through consortiums of European universities, such as EuroTeQ (2023), and projects around micro-credential projects, such as MicroHE and MicroCredX, that examine the demand for micro-credentials, (data) systems to support, as well as balancing needs of employers, society, individuals and educational/training institutions (Microcredentials 2023).

However, such approaches focus more on non-formal and formal learning, and do not fully embrace informal and experiential learning. Experiential learning, and recognition of prior learning are important aspects, of supporting up- and re-skilling of engineering practitioners.

It is this broader context of approaches to skills and competency development that this workshop seeks to gather some initial data to inform future collaborative research.

3 WORKSHOP DESIGN

The focus of this workshop was to encourage knowledge sharing and ideation within groups on the following questions:

1. What approaches are our organisations/institutions and partners taking to address these future-focused skills needs?
2. What are the challenges and opportunites that you see for CEE to develop the required future-focused skills?
3. What models (of design, partnership and delivery) do we need to meet these challenges (whether adaptations or creating models)?

This workshop aimed to gather stakeholders from industry, academia and learners together that are interested in up- and re-skilling in STEM and wanted to share and enhance models of collaboration (design and delivery) that will develop the required competences in a suitable agile and responsive manner.

The 60-minute workshop was divided into three sections:

1. Welcome and sharing of mapping of skills landscape trends over last decade, based on initiatives of European and International Organisations (such as EU, OECD, WEF and UN) from industry and academia, particularly around skills for sustainability (15 minutes)
2. Group discussions of approaches to CEE aligned to particular skills, considering opportunities, challenges, and models (25 minutes)
3. Sharing and discussion by groups (15 minutes)

4 WORKSHOP FINDINGS

4.1 Evolution of international skills agenda

A comparative examination of international policy and framework documents was undertaken to determine key skills agenda in the period 2011 to 2023. Documents were sourced from OECD (2011, 2013, 2014, 2015, 2016, 2018, 2019, 2021, 2022, 2023), ILO, EU (EACEA/Eurydice 2012; Fellows and Edwards 2016) and UNESCO (2015). Figure 1 below summarises the key skills priorities with a more detailed year-by-year analysis available.

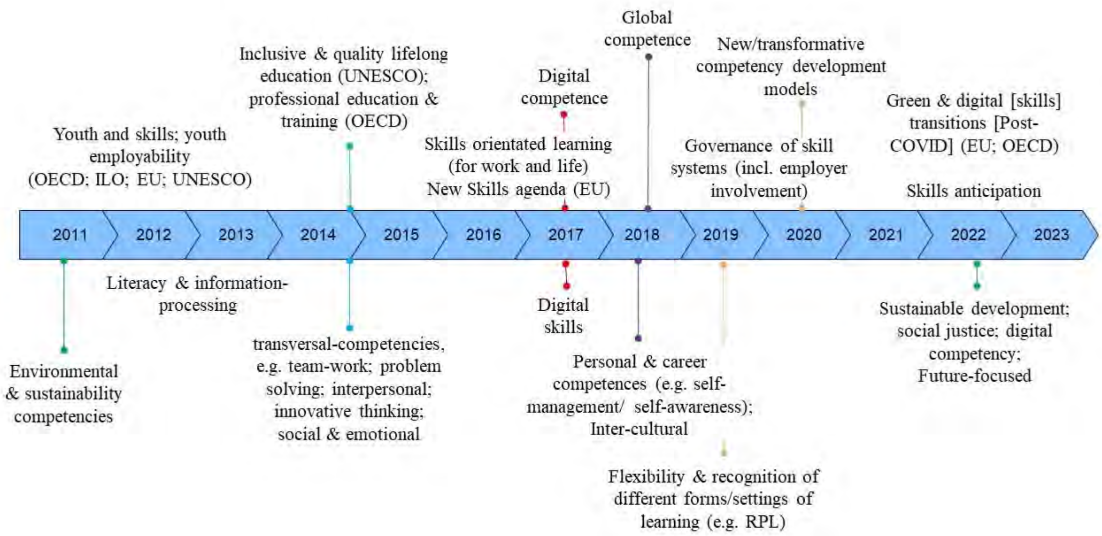

Figure 1: timeline of key skills priorities.

4.2 Approaches being taken to Continuing Engineering Education

One group discussed that there were emerging courses and offerings at their institutions, responding to specific local and regional industry needs, e.g. around biomedical. These courses were offered in different ways, including through MOOCs, and microcredentials. It was shared that within Ireland there is a co-ordinated approach to microcredentials being taken in Ireland and that a co-ordinated national approach is being taken (Higher Education Academy Ireland 2023). Questions were raised around the portability of these qualifications and the work of the EU was highlighted, for example, in 2021 the EU adopted proposals to work towards a web-based system for authentication and portability of microcredentials (EU 2022).

Additionally, the need for an eco-system between universities, industry and third-sector organisations was recognised. An example was shared of how third sector organisations (e.g. Engineers Without Borders UK) are providing materials to support universities to engage with engineering students around sustainability.

4.3 Challenges and opportunities for continuing engineering education

Similarly to the first group, this group saw opportunities for greater partnership, for the potential to access microcredentials across Europe and for these to be recognised (portable). However, greater clarity was required on what did organisations and practicing engineers want, and what was the best “configuration” of these different organisations to provide the best value, and avoid unnecessary duplication of effort.

In terms of challenges, then it is apparent from across several university attendees that strategic vision and support is required to make this a reality. Specifically, there needs to be a business case made at the institutional level for adequate resourcing, clarity on whether academic staff have to engage with this activity, as well as other resources (such as equipment for Data Science) to be able to provide these courses to up- and re-skill engineers.

Additionally, there needs to be some co-ordination in this ecosystem, so that you don't end up with multiple providers providing the same content, and with the more difficult courses being difficult to access, thereby leaving important gaps in meeting the needs of individuals, employers and society. This co-ordination challenge is further complicated by the different private and public organisations involved that have different strategies and associated business models.

4.4 Models to meet these challenges

The third group discussed how CEE was being provided in different institutions and how we might meet these challenges. In addition, extending the microcredential idea of the other groups, then the need for these to be stackable was required (so as to build towards a qualification, if desired).

Picking up on the point from the second group best value, then this group identified the need to recognise different forms of learning (formal and informal) and in particular the effective and efficient use of Recognition of Prior Learning (RPL). Whilst RPL is long recognised globally (e.g. in policy from EU), then there are still barriers to doing evaluating all forms of learning in an efficient manner, often due to the amount of time it takes for the applicant to collate evidence of learning, and then for the university to support and review evidence.

In terms of addressing the resourcing challenges identified by the first group (section 3 above), then company-based academic staff and instructors have an important role to play in the eco-system. However, there were questions raised around models to ensure quality control. Recognition is required that industry experts, acting as Associate Lecturers, are not necessarily trained as educators.

There are approaches in some countries that allow companies to get their in-house training to be evaluated and recognised on the national database of qualifications. For example, in Scotland, then under the oversight of the Scottish Credit and Qualifications Framework Partnership, organisations can credit-rate their internal courses with a Recognised Credit Rating Body (SCQF 2023); this an approach to provide quality assurance around courses that sit outside of educational institutions.

Finally, to enhance CEE offerings, then the use of personal and skills coaches was identified as a possible model.

5 CONCLUSIONS

The workshop highlighted that different institutions are at different points in adapting to their own regional and national contexts in providing CEE. There is a clear desire and recognition of the importance and relevancy of CEE to support up- and re-skilling and the need to collaborate with different shareholders. However, further sharing of practices are required to support institutions and stakeholders to propose evidence-based changes to better provide CEE in a collaborative ecosystem. Additionally, an important, fundamental finding for the further development of the strategy is that, due to the vital, synergistic and complex nature of lifelong learning, there are opportunities for the CEE/LLL SIG to collaborate with other SIGs – specifically Engineering Skills and Capacity Building. Therefore, this working group has an important role in interpreting the changing environment.

6 SIGNIFICANCE FOR ENGINEERING EDUCATION

Broadly, these findings align with those of Gomez-Puente et al. (2023) that compared practices across eight different institutions and found that a) resourcing CEE offerings is complex due to national regulatory frameworks, with some institutions creating Associated Private Companies to provide CEE courses, as well as different arrangements for payments to existing or Associate Faculty to deliver CEE offerings; b) that the courses offered are aligned to market need.

Further evaluation of the drivers and enablers of effective CEE are required, and the comparative sharing and analysis between institutions will be a focus of the SIG in the coming year.

In relation to the synergistic nature of how to respond to the developing skills needs, then meetings will be arranged with the co-chairs of the SIGs for Engineering Skills and Capacity Building.

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REFLECTIVE PRACTICE IN STEM DEGREES TO SUPPORT ADAPTABILITY AND LIFELONG LEARNING

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ABSTRACT

The benefits and importance of reflective learning is widely recognized for the development of STEM students. However, the implementation of reflective practices in the curriculum remains a significant challenge for educators. The main purpose of this paper is to help educators overcome this challenge: to better support students to develop their approaches to reflective learning, to better develop ownership of their own learning processes and to foster skills to support lifelong learning. First, we describe the results of a recent survey among engineering academics to look at the

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issue of reflective learning and the extent to which it is deployed in practice. This was then followed up with a linked workshop designed for STEM educators to exchange experiences on their reflective learning practices at SEFI 2023 conference at TU Dublin in September 2023. The outcomes of both survey and workshop showed a genuine positivity and consciousness of the need and benefits towards the implementation of student reflective practice with a range of approaches used to guide to the students in this. Despite the numerous identified hurdles of implementation, we propose interesting practices to make the implementation easier.

1. INTRODUCTION

Reflective practice in which students look back on their learning on a continual basis as a way of developing more robust and comprehensive understanding tailored to the individual is a key part of a number of cyclic learning models including those of Rolfe et al. (2001), Schön (1991), Gibbs (1988) and Kolb (1984). Such habits may also be considered to be important in helping with the lifelong learning processes of an individual once beyond formal education. It was therefore considered useful to investigate the extent to which reflective practice is used in engineering degrees, how it is supported and to look at the drivers and hurdles associated with its implementation. This was achieved via a review of prior work, via a survey and via a workshop.

2. BACKGROUND AND RATIONALE

2.1 The interpretation of Reflective Practice

In the academic literature, we can find a wide range of definitions for the reflective practice applying multiple approaches and interpretations to describe this concept. However, there is no consensus on the definition (Mann et al. 2009) and we consider it as a part of the process of lifelong learning allowing to individual learner to develop continuously their understanding. We define reflective learning as "*practice which involves the development of learning and understanding through self-review to help determine progress against goals and future learning needs*" and this can be argued is an important competence for both current students to help maximise their learning and as a competence for future professionals to take into their working life to ensure continued growth. Furthermore, there are different interpretations concerning the conception of reflective practice by educators including the development of students' (1) professional practice and (2) professional identity, (3) as well as their critical view on the course content (4) and their critical consciousness (Bailie et al. 2021). These interpretations of reflective practice from a professional and critical perspectives show the relevance of it not only in the educational but also in the professional context.

In Engineering Education, reflective practice has been identified as an important and emerging aspect of education in particular with regard to the personal, interpersonal and professional competences needed alongside technical competences (Sepp et al. 2015) for enhancing students' professional development. Similarly, Berglund's (2018) empirical study provided evidence of engineering students' professional identity development in their personal effectiveness (personal management), social and interpersonal competence (teamwork and communication), and the engineering professional role (engineering roles) through reflective practice. This work highlighted the potential benefits of reflective practices on engineering students' professional development laying the foundations to help graduates habitually identify and work toward development needs while progressing through their careers. However, we can observe that reflective practices in engineering education are mostly applied from a professional perspectives and there is a room of improvement for broadening the application of critical perspectives.

2.2 Implementation of reflective practice

Even if reflective practice is traditionally not included in engineering curriculum (Sepp et al. 2015), there is no doubt today about the relevance and usefulness of his integration and the concept of reflective practice is widely considered as a part of engineering education. The implementation of reflective practices improves significantly engineering students' academic performance as well as their social engagement through a more active participation in their team activities (Menekse et al. 2022). As a part of the lifelong learning process, engineering students' recognized the importance of reflective practice for their future professional career preparation as confirmed the empirical evidences of Eshuis et al. (2022). However, they were often not always satisfied with the tools or assessments used in their study program. Reflective reports were often regarded as the least meaningful in the eyes of the students. Reflective conversations with tutors were preferred by some indicating the important supportive role of teachers in this process. Similarly, Morgan et al. (2021:13) observed, despite an acknowledgement of the value of reflective practice, engineering students' showed reluctance and a generally low level of true reflection beyond simple reporting of facts. However, we should highlight that forcing students for practicing reflexive learning could be inappropriate and counterproductive (Finlay 2008). Therefore, teachers play an important role not only for giving clear assignment and guidance by supporting students' all along of their reflective practice in a persistent way (Cosgrove et al. 2014, Wallin et al. 2016) but also motivating and engaging them.

2.3 Survey outcomes

Prior to the workshop and to gain an overall feel for the use of reflective practice on engineering programmes, a survey was prepared. This looked at the perceived value of and the extent to which reflective practice featured in engineering programmes. It also explored barriers to implementation together with tools and approaches used by academics. Participants were academics or support staff associated with the delivery of engineering degrees and were drawn primarily from the SEFI and CDIO communities of educators. Full details on the methodology and results are reported elsewhere (Thomson & Kövesi 2023).

The survey showed that many practitioners were keen to embed reflective practice within their own degrees but they perceived greater hesitancy among colleagues and students. Barriers existed to implementation, most notable among these were pressures on time within the syllabus together with students not always being receptive to the approach. A range of approaches were used by the participants and their colleagues with presentations and end of term reports being among the most common. Free text responses highlighted some common issues around a difficulty in getting students engage and to reflect on and not simply report activities – "Students failed to properly engage and treated it as a last-minute afterthought". Successes were generally centred on providing students with consistent and regular guidance - “The structured nature helps students learn to reflect and enhance that skill” and “Reflection with a more obvious, immediate purpose improved engagement”.

3. WORKSHOP DESIGN

3.1 Workshop Introduction

To help disseminate and expand on these results, a workshop was held at the SEFI Annual Conference held at Dublin Institute of Technology in September 2023 (Fig 1).

Fig. 1. Workshop at the SEFI Annual Conference in Technological University of Dublin, September 2023

The workshop was open for all conference delegates according to their interest in reflective practice without requiring any prerequisite or experience. In addition to the two authors, 15 workshop participants took part in the activity.

3.2 Workshop Format

The participants in the workshop were first introduced to the topic and were given a brief summary of the results of the survey. They were then placed in self-selected groups of 4-6 and given worksheets to help stimulate discussion on:

- WHY – Why is it important to encourage students to engage in reflective practice?
- TOOLS – How can this be achieved?
- HURDLES – What hurdles are there in implementing reflective practice?
- TIPS – What tips can be used to make implementation easier?

The worksheets were then populated with thoughts, ideas and experiences of the participants using sticky notes. Groups were encouraged to expand on and link to the postings of others.

4. WORKSHOP RESULTS

Following each group's discussions around the prompts on the sheet, all participants were invited to come forward and share "key takeaways" with the wider group. See Fig 2. for a completed set of worksheets.

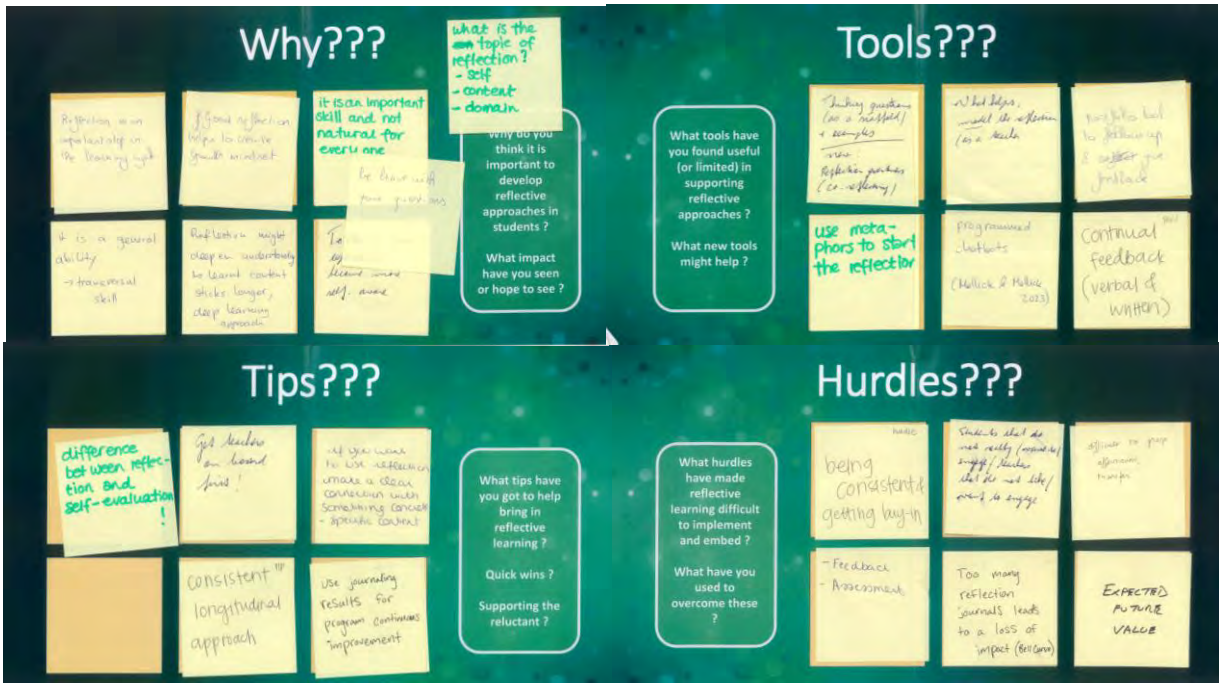

Fig 2. Typical worksheet sets from a group of participants at the workshop

Post-workshop transcription of ideas was carried out to preserve some of the key takeaway points.

Table 1. Summary of takeaway points

WHY	TOOLS
- Is key transversal learning skill - Helps students learn to learn - Develop lifelong learning into work - Strengthen & deepen understanding - Recognise progress & gaps	- Programmed chatbots - Thinking questions as scaffold - Co-reflections - Portfolios – maybe? - Showcases / metaphors / examples?
TIPS	**HURDLES**
- Provide good, regular feedback - Make it regular, continuous - Start small - Show it is not self-evaluation - Get staff on board	- Finding space in curricula - Getting staff & Student buy-n - Difficult to assess - No perceived immediate benefit - Not engineering, uncomfortable skill

5. DISCUSSION AND CONCLUSIONS

Both the results of the preliminary survey and the workshop showed a high degree of consensus on most of the key issues. The potential benefits of reflective practice are clearly identified and recognized as useful for engineering degrees especially for improving engineering students' professional development (Sepp et al. 2015, Berglund 2018). However, we have to point out that these benefits are predominantly interpreted from a professional perspectives emphasizing the importance of the development of (1) professional competences in the educational context and (2) students' capacity for lifelong learning in their future professional context. Even if the relevance of reflective practices' interpretation from critical perspectives is entirely acknowledged, our results showed that it is less prevalent in engineering education context.

Hurdles identified in both investigations highlighted the difficulty in finding space in the curricula to properly support reflective approaches and the difficulty in getting students to engage given the lack of immediate impact on marks or approach. For this reason, we would like to underline the key role of teachers and educators for motivating and engaging students in reflective practices. Similarly both identified clear scaffolding and support on a consistent basis being a necessity if reflective practice is to be embedded.

The workshop also brought in new perspectives with the application of emerging technology, for example the potential for AI chatbots to act as a neutral third party to help draw out reflections was considered. Also, it could be an interesting support for teachers and educators and could be considered as an excellent opportunity to facilitate the not only the co-creation but also the assessment of reflective practice that perceived as one of the major difficulties of implementation. In accord with the empirical finding of Cosgrove et al. (2014), our findings showed that persistence and continuity/regularity are important elements of the implementation of reflective practice.

On the basis of the findings presented in this paper, in the future we would like to continue our investigations on the topic of reflective practice's role and implementation in engineering degrees by adding students' perspectives. We consider that further research is needed to have a better understanding how to enhance students' motivation and engagement in reflective practice.

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HOW DIVERSE ARE GLOBAL PERSPECTIVES ON DIVERSITY, EQUITY, AND INCLUSION IN ENGINEERING EDUCATION?

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ABSTRACT

The SEFI Special Interest Group on Gender & Diversity has recently been renamed as Diversity, Equity and Inclusion, broadening the definition from a focus on gender

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to embrace a wider range of diverse identities – such as language and cultural background, religion, physical ability, and socioeconomic status – and to promote and support equity and inclusive practices within SEFI and beyond. In the process of redefining the Special Interest Group's mission, it has become clear that definitions of diversity, equity and inclusion may vary considerably between different contexts and institutions. Therefore, it is relevant for the engineering education community to share and examine how these terms are understood and implemented in their own institution and in other contexts around the globe. In this workshop, invited panelists from different continents and countries (United Kingdom, United States of America, Venezuela, South Africa, People's Republic of China), and representing different engineering education communities across the globe (SEFI, American Society for Engineering Education, Research in Engineering Education Network, South African Society for Engineering Education) presented their perspectives and experiences on diversity, equity and inclusion. This was followed by small group discussions, during which SEFI 2023 participants examined their personal and the panelists' perspectives with the facilitators. Several main conclusions emerged from these exchanges, all imbued with the awareness that context is crucial and that sustained dialogue with stakeholders across cultures and continents through various channels within and beyond the Special Interest Group of SEFI should be supported.

1 BACKGROUND AND RATIONALE OF THE WORKSHOP

Diversity, equity, and inclusion have increasingly become highlighted within engineering education today in Europe (Direito et al. 2021) and beyond (London, Murzi, and Litzler 2022). The SEFI Special Interest Group [SIG] Gender & Diversity has recently been renamed as Diversity, Equity and Inclusion [D-E-I], broadening the definition from a focus on gender to embrace a wider range of characteristics and identities. These characteristics include but are not limited to language and cultural background, religion, physical ability, and socioeconomic status (SEFI n.d). In the process of redefining the SIG's mission, it became clear that definitions of D-E-I can vary considerably between different contexts and institutions. This observation confirms the results of a study by Pineda and Mishra (2023), who conclude on the basis of a computer-assisted content analysis of 2378 academic publications that 'diversity' has become a dominant theme only in some regions across the world and that where it appears, the concept has been interpreted in different ways, sometimes according to the discipline in which it occurs. In addition, 'diversity' policies in higher education have increasingly become a focal battleground for emancipatory forces and culture warriors alike (e.g. Harris 2018; Powell 2023; Saul 2023).

Therefore, it is important and timely that the engineering education community share and examine how 'diversity' and cognate terms are understood and implemented in their institutions and in engineering education contexts around the globe. As an initial step in this exploration, the SEFI SIG D-E-I put forward the workshop that is reported on in this contribution as its designated workshop for the annual SEFI conference held at TU Dublin on September 11-14, 2023 (https://www.sefi2023.eu/).

2 WORKSHOP OBJECTIVES

The one-hour workshop was designed so that participants could attain the following three objectives:

i. an increased awareness of how D-E-I is understood and implemented in a variety of engineering education contexts around the globe;
ii. a deeper insight into what elements are foregrounded in D-E-I policies and practices in their own institutional context and what is common or left out in comparison with engineering education contexts elsewhere; and
iii. a keener idea of how participants could act in their local engineering education context to realize the values of diversity, equity and inclusion.

3 WORKSHOP DESIGN

The workshop session included the following steps.

1. Introducing the workshop objectives, structure, and facilitators;
2. Collecting initial participant perspectives on the following two questions, whereby participants entered their responses in the open response format on Mentimeter (mentimeter.com).
   i. What does diversity mean to you?
   ii. What is important about diversity to you?
3. Invited panelists from different continents presented their perspectives on D-E-I. The panel included the following notable speakers:
   - *Fiona Truscott* and *Natalie Wint* (University College London, U.K.); Co-chairs of the SIG D-E-I of SEFI;
   - *Homero Murzi* (Virginia Tech, U.S.A.); Past Chair of the American Society for Engineering Education (ASEE) Commission on D-E-I, Incoming Chair of the Research in Engineering Education Network (REEN);
   - *Karin Wolff* (Stellenbosch University, South Africa); President of the South-African Association of Engineering Education (SASEE);
   - *Xinrui XU* (Huazhong University of Science and Technology, P.R. China); Researcher in engineering education and curricular development.

   Except for the last-mentioned speaker, who had pre-recorded her contribution, the panelists were present in the room. All speakers were invited to respond to the following questions.
   i. To your knowledge, how prominent has D-E-I been in recent times in the discourse on engineering education in your region?
   ii. In your experience, which D-E-I issues have been at the forefront of people's attention in your region in engineering education?
   iii. In your opinion, what have been the achievements and weaknesses of the current discourses and actions around D-E-I in engineering education in your region?
4. Small group exchanges, during which participants examined their personal and the panelists' perspectives with the facilitators acting as note-takers. The guiding questions for these small group exchanges were as follows:

i. How did the panelists’ views and experiences resonate with your own views and experiences?
ii. Was there something that helps you to think about or act in your own institutional context?

5. Conclusions to the workshop: main takeaways and the road ahead.

4 WORKSHOP RESULTS

The workshop was attended by approximately 50 participants and 7 facilitators / panelists.

4.1 Initial participant perspectives on diversity

The question ‘What does diversity mean to you?’ yielded 41 responses. The following synthesis statement is our attempt to combine the various elements of the answers we received into one full sentence.

> Diversity is… bringing together people from a variety of backgrounds, with different experiences and perspectives, valuing their unique qualities as equal to our own by listening to their voices and considering them as resources for enhanced creativity and as gifts for greater joy.

Quite some responses specified one or more dimensions of diversity. These responses covered all categories of the traditional ‘Big 8’ model for classifying human variation in higher education (Plummer 2003) with the exception of sexual orientation: ability (mental/physical); age; ethnicity and nationality; gender; organizational role and function; race; religion. In addition, participants referred to dimensions of diversity in culture; disciplinary background; language; learning style; and upbringing.

There were 58 responses to the second question, ‘What is important about diversity to you?’ (participants could submit more than one response if they chose to do so.) Overall, these responses demonstrated that participants realized the close interconnections between diversity, inclusion, and equity. Many responses referred to the importance of feeling welcome; included; recognized; respected; affirmed; and valued. Participants also pointed out the significance of leveling the playing field and giving everyone a fair go. Justice, democracy, and kindness were some of the values that were named. Other responses drew attention to the fact that diversity requires critical self-reflexivity; awareness of privilege; the ability to deal with emotions and discomfort; and empathy.

4.2 Panelist perspectives on Diversity, Equity, Inclusion

Fiona Truscott and Natalie Wint, Co-chairs of the D-E-I SIG of SEFI, explained that with the SIG they would like to focus on gaining a better understanding of what priorities there might be in different national and institutional contexts. Within Europe, D-E-I in engineering education has been primarily focused on gender. Although this remains an important issue, the SIG has changed its name this year to widen the scope to different aspects of identity and personal background. Awareness of D-E-I in engineering education in Europe has been on the rise and has increasingly been comprised in legal and accreditation frameworks. It has also been incorporated into agendas for sustainability, social justice, or global competences. However, the co-chairs regretted that there is also a discourse that puts an economic focus as the reason for increasing diversity and they stated that an increased attention to intersectionality would also be welcome. They applauded the fact that the workshop offers a forum for discussion and concluded that the SEFI SIG can take follow-up action.

Homero Murzi, Past Chair of the ASEE Commission on D-E-I and Incoming Chair of REEN, offered both a North-American and a Latin-American perspective to the panel. He narrated how being a Latino man in Venezuela only became a salient feature when he moved to the US. Contextuality has been a determining factor in his personal experience. In Venezuela, he researched how to make classrooms more inclusive, for instance towards students who feel they have to hide aspects of their identity that go against norms in society. Moving to the US he acknowledged he needed several years to understand what particular diversities meant from a US historical perspective and realized how even within the country, context makes a difference. On the positive side, he recognizes there has been substantial funding for research on broadening participation and the inclusion of particular groups both in the US (the Latinx space; the Afro-American experience …) and in Venezuela (e.g. specific indigenous groups). However, he regretted that sometimes we prescribe solutions that have not fully involved the people being affected by them. He also deplored the fact that research into teaching over the past thirty years has often not been translated to the classroom, resulting in a cycle where the same issues reappear again and again. Lastly, he wished that basic values of being human, kind, and empathetic gain wider recognition.

Karin Wolff, President of SASEE, indicated that in the South African context, D-E-I is embedded within a wider national transformation program. Based on a constitution that recognizes the past injustices under the apartheid era and upholds human dignity, the National Planning Commission of the Presidency of the Republic of South Africa (2012) developed a comprehensive national development plan for a structural socio-economic transformation of the country. In contrast to many other contexts where the protection of minorities is at stake, apartheid brought about a radical discrimination of the majority of the population. In engineering education, this transformation has already resulted in structural achievements on the ground, including a revised national qualifications framework, foundation programs, academic literacies programs, and other community engagement programs. However, she indicates that coordination between these programs has been neglected and major problems persist in reality. In terms of enrolment in engineering education, substantial progress has been made concerning the participation of females and the non-white population. Graduation statistics show a starkly different picture, though, as female professionals and black graduates remain vastly underrepresented. A number of additional burning issues need to be addressed as well, including the engagement of students in the transformation processes and a sustained decolonization of the curriculum.

Xinrui XU is an engineering educational researcher at HUST in China and a former career service consultant for university students at Purdue University. She also speaks as a former international student in the USA, a perspective she describes as a D-E-I experience on a daily basis (see also Xu, Wei, and Cao 2023). She explained that in engineering education in China, women’s issues are most prominent in the discourse although they may not be framed within a D-E-I framework. Women live with the knowledge and the fear that they will fall behind when they decide to get married and have a child. Employers commonly assign women with less central and less challenging tasks because they expect that they will take care of their family at some point. As a result, it is almost impossible for female engineers to compete with their male counterparts. The fact that there are so few female role models and leaders exacerbates the situation. She hopes that her research will shed further light on these issues.

4.3 Small group exchanges on D-E-I

Participants formed self-organized groups of about 4 people. Each facilitator and panelist joined a group to take notes on a Padlet form (https://padlet.com). Several main conclusions emerged from these exchanges, all imbued with the awareness that context is crucial.

- Gender balance remains a burning issue in engineering education yet in some institutions, gender is not seen as part of diversity efforts.
- Some aspects of belonging merit closer attention than they have received so far, including the inclusion of international students (alongside domestic minority groups), or students in a school environment where the dominant language or favored learning style is experienced as foreign.
- Conversations about D-E-I have become increasingly polarized and politicized. In some parts of the USA, D-E-I policies and practices today face legal obstacles.
- A well-known pitfall for D-E-I is that it risks becoming a purely technical matter of checking boxes and token inclusion. This can give the organization a false sense of achievement of inclusion. What is needed instead is a genuine and sustained conversation, the abolition of exclusive systems and practices, and the introduction of integrated support approaches.
- Change starts on the ground; therefore it is crucial to remove ignorance and raise awareness of diverse diversities at the institutions. The question is asked whether this should be provided as optional or compulsory professional development for educators.

5 CONCLUSIONS

This paper reported on the dedicated workshop of the SEFI Special Interest Group ‘Diversity, Equity and Inclusion’ at the first annual conference since its name was changed to reflect a more comprehensive interest in diverse diversities. Together, workshop participants unpacked their understanding and experiences of D-E-I in their respective engineering education contexts. Testimonials from an expert panel drew attention to D-E-I practices and experiences in Europe (UK and SEFI SIG DEI community), Latin America (Venezuela), North America (USA), Africa (South-Africa) and Asia (P.R. China). Tokenism and whitewashing (an apt term given that white light combines the full diversity in the color spectrum) were condemned in favor of a genuine on-going dialogue involving all stakeholders and concerted action. Context emerged as a critical factor, recognizing the cultural legacies and power relations of each context. There are indeed diverse perspectives on diversities and the conversation is conducted in various languages.

We can sense a keen awareness that this workshop was just the first step in a joint pursuit to gain a deeper insight into the discourses on diversity, equity and inclusion in engineering education around the world. In the authors' eyes, this is not just an academic exercise but a praxis, a 'situated practice which must include morally grounded action aimed at fairness and justice' (Ladegaard & Phipps 2020, 75). We are consequently committed to engaging in a sustained dialogue with stakeholders across cultures and continents through various channels (conferences; webinars; podcasts; publications …) within and beyond the Special Interest Group of SEFI. And we hope dearly that you will join us and let your voices be heard.

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We express our gratitude to the co-chairs of the Special Interest Group on Diversity, Equity and Inclusion of SEFI for trusting us to develop and conduct the designated SIG Workshop for the SEFI 2023 Annual Conference. A special call out goes to Lisa Schibelius (Virginia Tech) for designing the slideshow. Above all, we would like to thank the invited panelists and all participants for co-constructing the insights on D-E-I on which we can all build for the betterment of engineering education across the world.

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Integrating Learning Analytics into Engineering Education: Design Strategies for Teachers

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***Conference Key Areas**: Education about and education with Artificial Intelligence, Innovative Teaching and Learning Methods*
***Keywords**: Learning Analytics, Indicators*

Background, Rationale and Motivation

While reflecting on the role of engineering education for a sustainable world, one must consider one of the most important gamechangers in education of this century: the use of big data, and within it, Learning Analytics (LA).

LA is defined as “the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs” (Gasevic *et al.,* 2019; Long *et al.*, 2011). LA generally comprises three major themes: indicators and predictors, visualizations, and interventions (Gasevic *et al*. 2019; Brown, 2012) which are interconnected. For instance, specific Learning Analytics indicators can be developed and subsequently used to visualize critical areas of the learning experience to provide the basis for the design of class interventions. Some examples may include: basic summary indicators such as total learning time online and total number of learning sessions (Conijn et al., 2017), study irregularity indicators such as irregularity of learning time and entropy (Jovanovic et al., 2019), and indicators of resource accessing such as number of file downloads and number of forum posts (Park et al., 2016). Indicators have been found to be predictive of students’ learning outcomes (Conijn *et al*., 2017), beneficial forms of learning (Liz-Dominguez *et al.*, 2022) or student well-being (Sher *et al.*, 2022).

One important aspect of learning behavior often explored is student engagement, that has always been considered essential for successful learning, which modern LA methods have allowed us to get a deeper understanding of this process (Saqr & Lopez-Pernas, 2021). Student engagement is a fluid and dynamic process, and can change over the duration of the course, year, or even the whole study program (Saqr & Lopez-Pernas, 2021). Such trajectories are difficult and costly to measure with more traditional methods (such as surveys or interviews) (Panadero, 2016).

Educational professionals can utilize these insights to identify students’ needs and design educational interventions that can help students improve (Charleer *et al.*, 2016). Big data from individual students can be used to create personalized learning approaches and targeted interventions that account for particular needs and goals (Zhang et al., 2020). Interventions would need to be done early enough during a course so that students can adjust their learning behavior over time. Also, teachers would need to design their course and interventions so that students' online learning behavior generates data required by the indicators.

Workshop activities

We will initially present the background of LA and set the scene on type

of indicators and tools for data visualisation. We will use the workshop design of Hrastinski (2021) so that participants consider their own courses and work in small groups. The groups will be based on type of indicator (to support student learning outcomes/student wellbeing/personalized learning and student engagement).
In this way each participant can get useful information for its own course from this workshop. The following points will be considered within the groups:

1. Background – Share your own module, e.g. name, purpose, level, scope/credits, approximate number of participants
2. Design -Describe and motivate the indicators incorporated in the course design
3. Evaluate - How should the indicators be visualized and interpretated to make informed decisions?
4. What potential ethical challenges may arise, and how can they be effectively addressed?
5. Share - How can lessons learned be shared with colleagues?

We will use posters in each 'round table' to record the outputs of the idea generation. Finally, we will bring all the ideas together in a plenary discussion where all participants can share lessons and challenges they might face.

Presentation	20 min
Group work	15 min
Plenary discussion	15 min
Concluding remarks	5 min

Workshop objectives

This workshop provides an opportunity for engineering educators to learn about LA, how it can be incorporated in their course design and what LA literacy do teachers and students need to take advantage of this approach. This will in turn improve student learning outcomes, address student behaviour with respect to performance and improve personalized learning (Akhila et al, 2020).

One aspect that we will cover throughout is the ethical usage of big data in education. Using technology that can store and identify the trace data of individual students leads to the possibility of tracking learners (Pardo & Siemens, 2014) and hence give rise to ethical and privacy issues that require understanding and active effort from educators, researchers, and policy makers to solve. We will present some of the frameworks and models that have been created for this (Kitto & Knight, 2019). At the end of the workshop participants would be able to a) list different indicators (e.g. to support student's achievement of learning outcomes and or student well-being), b) grasp the basis of course design to generate useful data for different types of indicators in an ethical, transparent and responsible manner and c) identify tools that can support the interpretation of data that supports their decisions on course design in engineering education.

Workshop outcomes

The workshop discussed broadly the opportunities provided by LA and was visited by an enthusiastic range of researchers and practitioners looking to improve students learning in engineering education through the use of educational data. The presentation clarified the use of data by teachers to improve their course, by students to improve performance and by the institution to improve student retainment and wellbeing and overall management information.

After setting the scene in the presentation the group naturally split into three differently focused groups. There was a group grasping the set up of LA to improve student engagement, sharing experiences and discussing further on the possibilities presented. There was special interest in the direct feedback loop towards students and on 'how to communicate' the outcomes of the data analyses to improve student engagement. Another group focused on monitoring student wellbeing, discussing the friction between LA on course level and balancing the student workload on curriculum level. Furthermore, the ethical considerations regarding opting out vs informed consent on the use of student data rose the question: 'what is really helping the student?'. Here, also the importance of combining offline and online student data was stressed. The third group discussed in more detail the use of LA to measure student self regulated learning and the use of resources. The group discussed the way in which the feasibility of unobtrusive measurement of students' learning characteristics can be tested, and the results of a working paper in which this approach was shown to work well for three of four dimensions of self-regulated learning. The discussion highlighted the need to think carefully about how to design a course in such a way that it delivers useful input for a learning analytics approach.

Conclusions

Using LA starts at most institutions with smaller scale pilots in individual courses. The set up of LA requires a lot of investment by different stakeholders at the institution because on the one hand little is known yet and on the other hand the local legislation and privacy requirements prohibit a 'one size fits all' solution. Unfortunately, small scale pilots do not provide the needed overall picture that is required to compose a meaningful and personalized analysis and advice for students. For student engagement, student wellbeing, student performance and the improvement of courses a lot of different dots have to be connected, in the ideal world this would be online as well as offline indicators.

However the small scale pilots deliver a meaningful and essential contribution to the development of LA at scale. The use of LA for self regulated learning is an example. LA pilot projects are pieces of the puzzle to realize the above ideal world and contribute to the large scale adoption of Learning Analytics that is an unevitable development in the current developments of big data. Despite differences in regulation and privacy, the experiences of different institutions can together optimize the development of learning analytics at scale.

Significance for engineering education

This workshop provided an opportunity for engineering educators to learn about LA and how to incorporate it in engineering education and course design.

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SUPPORTING UNDERGRADUATE ENGINEERING STUDENT MENTAL HEALTH

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***Conference Key Areas**: Equality Diversity and Inclusion in Engineering Education, Recruitment and Retention of Engineering Students*

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1 MOTIVATION, BACKGROUND AND RATIONALE

The culture within engineering education can lead to the normalization of stress, which has the potential to impact student mental health. In particular, there have been reports on the perceived stress of the engineering education environment (Prakash and Bajpai 2015, Balaji et al 2019, Jensen and Cross 2021, Wilson et al 2022), perceived difficulty of an engineering degree (Engineering UK 2020) and an increasing body of quantitative and qualitative evidence highlighting mental health and wellbeing challenges experienced by engineering students. Further, engineering students are resistant to seeking professional help for their mental health (Lipson et al 2016, Wilson et al 2020, Wright et al 2021, Beddoes and Danowitz 2022, Jensen et al 2023), which has been proven reduce the potential for progression to more chronic or severe mental health disorders (Mitchel, McMillan and Hagan 2017). Investigating the mental health and wellbeing of engineering students specifically is important due to a global lack of engineers and increased need for engineering graduates (Pozniak 2017, Williamson 2018, Engineering X 2020). While the reasons for this skills deficit are not clear, calls for education reform to address the problem have been growing for some time (Graham 2012, Poole, Khan and Agnew 2017, Das, Keinke and Pistrui 2020, Phillips 2022) Further, more engineers are leaving the sector internationally due to burnout (Phillips 2022) and this can differentially impact female engineering professionals (Ronen and Malach Pines 2008). Concerns are also being raised about the mental health of engineering professionals in the UK (Equal Engineers 2022, Flaig 2022) and beyond (Sheedy 2022, Wilson and Goldberg 2023).

The literature on mental health in engineering highlights the importance of shifting the narrative around prioritization of mental health in engineering. Through this workshop, we aim to provide engineering faculty with the tools to normalize discussions around mental health in the classroom and promote a culture of wellness in engineering. Through creating a culture that is supportive of mental health in the engineering classroom, we aim to create an engineering workforce that understands the importance of prioritization of mental health as they progress through their careers.

2 WORKSHOP DESIGN

The workshop was designed to enable participants to be able to:

1. Define the current state of research on mental health in engineering;

2. Reach out to and support students who might be struggling;

3. Identify research-based strategies for integrating good mental health into the classroom.

2.1 Structure

There were three high level aims of the workshop, which were aligned with the learning outcomes. The major focus of the workshop was to provide faculty with tangible and research-based ideas to integrate mental health and wellness into the classroom (Tait, Hancock and Bissett 2022, Wilson and Jensen 2023).

Introduction (10 minutes)

The introduction highlighted literature on how mental health concerns can differentially impact students based on their social identity. It also highlighted that engineering students in distress are less likely to seek help for their mental health than students of other disciplines. The introduction provided participants with current knowledge on the state of mental health in engineering internationally.

Facilitated discussion (10 minutes)

There was a facilitated with delegates on their experiences and concerns associated with mental health in engineering. We then asked delegates to discuss common engineering student stressors and then they were asked which stressors impact all students vs. which stressors might differentially impact students within their courses.

Key mental health strategies (10 minutes)

We highlighted key research-based strategies for reaching out to students who might be struggling and encourage faculty to become referral agents for students in mental health distress (Wright et al. 2023, Wilson and Goldberg 2023). Examples included:

1. Distributing student check-ins
2. Modeling wellness in the classroom;
3. Creating a supportive community;
4. Integrating wellness activities (mindfulness, breathing, etc.);
5. Providing students with resources;
6. Creating syllabus statements.

We integrated a breathing exercise into the workshop to allow delegates to see the influence on the classroom environment.

Facilitated discussion (10 minutes)

We facilitated a discussion with delegates on challenges and opportunities with integrating mental health and wellness into their own engineering classroom. This was with the intention of enabling and informing post-workshop reflection on their own practices and to help them identify where they could enhance the culture of their classroom given that there will be different practices in different institutions.

Guidelines for wellness in the classroom (10 minutes)

In addition to strategies for integrating and modeling wellness in the classroom, we provided guidelines for creating an inclusive classroom environment through integrating flexibility and accommodations into the course structure.

Toolkit overview and workshop washup (10 minutes)

The final part of the session introduced the toolkit we have provided to participants and provided a final summary of topics covered in the workshop.

3 RESULTS OF THE WORKSHOP

Throughout the workshop, a frank and open discussion was facilitated on the challenges facing engineering faculty and students. Key areas of concern related to student mental health included: 1) it was unclear how to identify and provide students with the appropriate form of help, 2) the number of steps required to access help, 3) students being hesitant to ask for support due to the faculty-student relationship, and 4) students waiting until they reach a crisis to access support (Figure 1).

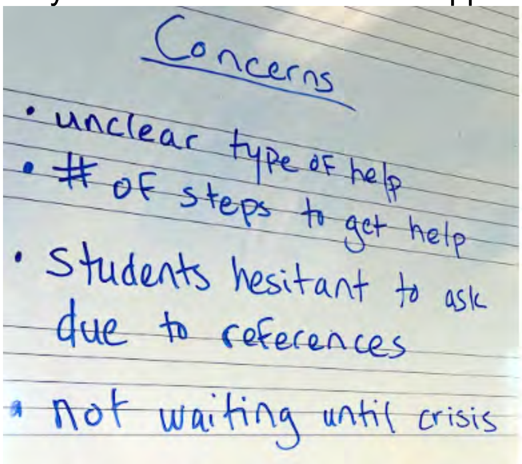

Figure 1. Participant concerns related to student mental health and wellness

We then had a discussion around stressors in engineering and how those stressors might differentially impact students within their classroom (Figure 2). Stressors that were identified as impacting all students include: homework, overlapping exam schedules, fear of failing, grades, pre-requisite sequences and faculty interactions. Stressors that were identified as potentially differentially impact students include: finances and course overload. Other stressors that were identified include: administration and policies, competition, high expectations, group projects, power structures, culture, climate change, careers, priorities, life/family, not belonging and connecting with faculty.

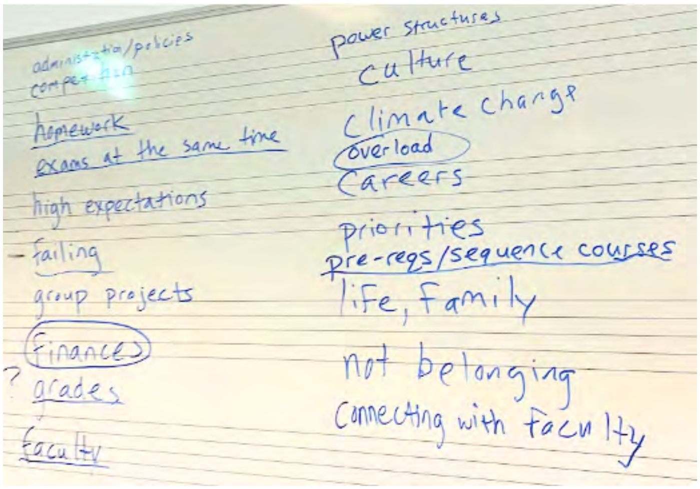

Figure 2. Identified engineering student stressors. Stressors that are underlined were identified by participants as impacting all engineering students. Stressors that are circled were identified by participants as only impacting some students in engineering.

Finally, we talked to faculty about strategies that they use within their classroom to support mental health and wellness (Figure 3). Key strategies that were implemented by those in the room included: 1) identifying and reaching out to students that are not present within class or might be showing other signs of mental health distress, 2) putting up posters around the engineering space to encourage prioritization of mental health and highlight mental health resources and 3) making yourself known as someone that students can reach out to if they are in need of support.

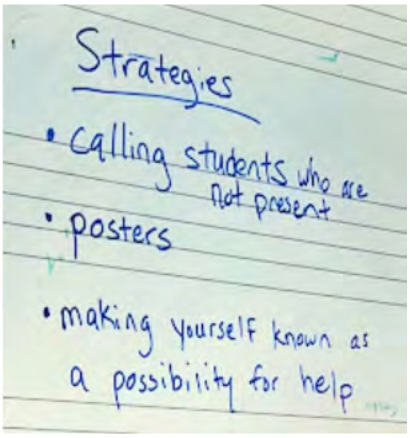

Figure 3. Strategies that participants use to support student mental health and wellness

4 CONCLUSIONS

The workshop aimed to fill a gap in faculty knowledge and increase confidence in their ability to act as referral agents for students in mental health distress and was tailored for faculty and administrators in engineering who would like to create an engineering environment that is supportive of student mental health. Delegates will left with a toolkit of research-based strategies for developing a classroom environment that promotes prioritization of mental health and wellness. The toolkit included a mental health advocate worksheet that they can utilize to document both institutional and regional mental health resources. Additionally, this worksheet provides guidance for recognizing students who are struggling with their mental health, as well examples for how to reach out to students of concern. Delegates will be able to modify the toolkit to be appropriate to their institution.Opportunities for collaboration and further research and/or interventions to support engineering student mental health and wellbeing were identified. Further, workshop participants recognized that institutional support is needed to support engineering faculty to empower them to make impactful change.

5 SIGNIFICANCE FOR ENGINEERING EDUCATION

There has been an increase in the prevalence of mental health concerns in students globally. Because of the role that faculty play in student's lives, they are often in a position to recognize signs of mental health distress (Kalkbrenner 2016). Further, students often approach faculty as a source of support when they are struggling. Despite this, studies have shown that faculty do not feel prepared to support their students who are struggling with their mental health (Albright and Schwartz 2017, Wilson, Hammer and Usher 2021). Therefore, this workshop aims to fill a gap in faculty knowledge and increase confidence in their ability to act as referral agents for students in mental health distress. Further, because the current engineering training environment contributes to what has been called a culture of stress within engineering (Jensen and Cross 2021), we aim to provide faculty with a toolkit to change this narrative and create a training environment that is more supportive of student well-being.

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SUPPORTING ENGINEERING STUDENTS WITH DISABILITIES: PROMOTING AWARENESS AND SHARING GOOD

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1 BACKGROUND

The amount of literature that focuses on diversity and inclusion within engineering education continues to grow. However, research traditionally focuses on gender, and despite the United Nations Convention for the Rights of Persons with Disabilities (CRPD) being passed in 2016, there is still a lack of work which describes the experience of students with disabilities.

This is particularly pertinent given the increasing number of engineering students with non-visible disabilities (NVDs) including ADHD, dyslexia, dyscalculia, dysgraphia, dyspraxia, autism, and mental health conditions, whose outcomes are, in part, dependent upon the reasonable adjustments they receive. These students face many barriers, for example: bias around decisions regarding accommodations (Druckman, Levy, and Sands 2021); dependence of grades on suitability of reasonable adjustments (Singer, Golan, Rabin and Kleper 2020); and stigma over disclosure of disability (Pearson Weatherton, Mayes and Villanueva-Perez 2017). Non-academic factors such as systemic and personal barriers are more likely to affect students with disabilities, this being especially true within engineering where the culture and climate limits potential for cognitive diversity to impact engineering. Whilst the number of engineering students with NVDs is increasing, the disability employment gap indicates that students face barriers to opportunities within the profession (Pearson Weatherton, Mayes and Villanueva-Perez 2017). There is also insufficient academic training and understanding of how disabilities affect learning and academic performance, and staff attitudes toward disability support have been shown to have a direct impact on academic success (Pearson Weatherton, Mayes and Villanueva-Perez 2017).

These issues are heightened by the learning experience within higher education (HE), which varies substantially from that within schools, in which learning is often highly structured. At the same time there is shift in pedagogical approaches used within engineering education (Dusek et al. 2018) and a higher degree of unstructured time and informal instruction. In comparison, existing accommodations have been developed for traditional learning environments and it is unclear whether reasonable adjustments allow students to develop the professional skills (e.g., flexibility, executive functioning) increasingly required by engineering employers. This alongside, the non-academic factors which can affect disabled students, may result in lower levels of self-efficacy and reduced outcomes, particularly with respect to employability, this reducing the potential for the profession to benefit from their abilities which include strong divergent thinking, creativity, innovation and risk-taking (Hain et al. 2017).

Although the use of labels can help us understand ourselves and others, and often allow access to support and resources, they can also be problematic. For example, they can only tell you so much about a group rather than an individual and thus do not encourage the use of student-centred approaches.

2 MOTIVATION

The development of this workshop was a result of the relative lack of discussion about NVDs within the SEFI community, something which becomes more noticeable as the number of engineering students with NVDs increase, and as engineering pedagogies change. We also acknowledge that the way in which disability is treated is also likely to vary in different geographical locations, and there is a need for comparison and sharing good practice across European countries. Our objectives thus included: comparing the processes and practices which impact students with NVDs in different contexts; amplifying practices that foster inclusion of disabled engineering students; and creating opportunities to share insights and practice.

3 WORKSHOP

The workshop consisted of the following activities:

1.) Plenary:
- An introduction to the workshop format and facilitators and discussion of ground rules such as respect and confidentiality.
- Terms used and scope of the workshop. Our use of non-visible disability (NVD) was related to physical, mental, or neurological conditions that limit a person's movements, senses, or activities that are invisible to the onlooker. Whilst we recognised the existence of a range of NVDs, physical conditions were considered beyond the scope of this workshop which focused specifically on neurological conditions such as ADHD and ASD, as well as mental health conditions.
- An introduction to some of the issues that may be present within engineering education. For example: different way of processing which often require more time; losing sight of objectives which may mean students do not finish tasks; difficulty with time & self-management

resulting in late, unstructured ways of working and difficulty synthesizing; difficulties understanding expectations, especially when requirements are very open; difficulties in prioritizing or distinguishing between major and minor issues; misinterpreting questions/explanation or social situations; sensory overload which may involve getting emotional or withdrawing; and anxiety induced by unfamiliarity or unpredictability.

- Definition of reasonable adjustments or accommodations: "making changes to tasks, environment, or the way things are done to provide equal access to education without changing the fundamental learning objective of a course" and discussion of the process that occurred before adjustments could be made (Figure 1).

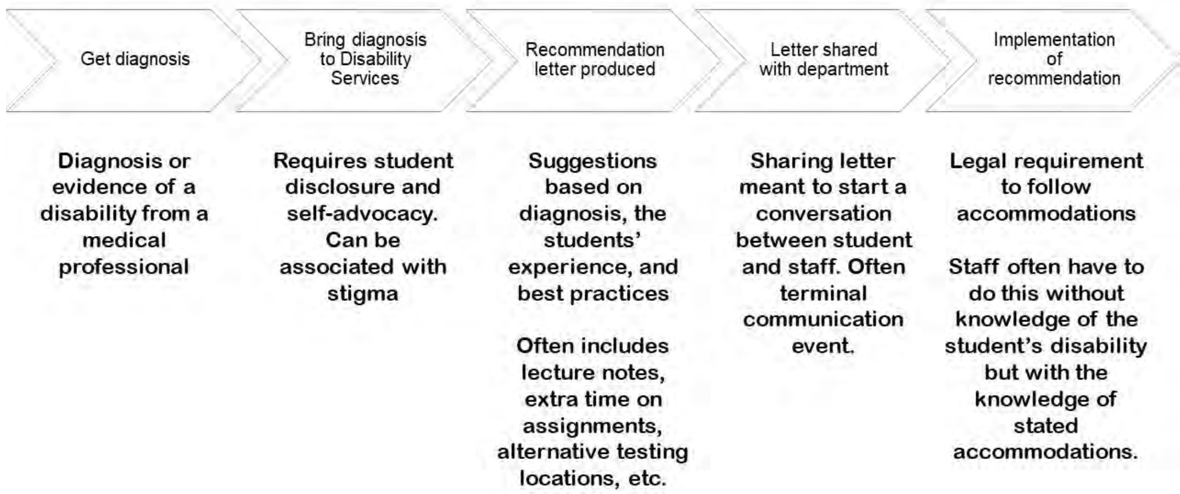

Figure 1: Stages of the processes which is typically followed in order for a student with NVDs to receive reasonable adjustments or accommodations.

2.) Activity: Participants discussed variations in the definitions of disability and institutional policy with respect to requirements for support and reasonable adjustments within different contexts.

3.) Plenary: Discussion of UDL and UDL pyramid (AHEAD). It was recognized that a continuum of support is required for inclusion. Participants were introduced to The Inclusive Education Pyramid (AHEAD) which encourages us to aim to move supports as low down the pyramid as possible to 'Universal Design for the majority of students' whereby UDL principles are incorporated into the mainstream teaching, learning and assessment practices of an institution and thus the majority of students can have a successful learning experience without additional support being necessary. The UDL Guidelines (UDL 2018) were suggested as a tool for the implementation of Universal Design for Learning. The framework offers a set of concrete suggestions that can be applied to any discipline (including engineering) to ensure all learners can access and participate in meaningful learning opportunities.

4.) Group activity: Participants provided examples of learning and teaching activities in which they needed to support a student with a NVD. They were invited to share concerns and experiences, as well as ideas for classroom policies and practice including: support for transition to university; examples of practices and teaching interventions that support students with NVDs.

5.) Plenary: The workshop finished with recommendations and next steps. We suggested:

- asking students with NVDs what they need;
- ensuring multiple ways in which to access course material and feedback e.g., lectures and (old) videos;
- providing detailed answers to coursework;
- providing written and verbal feedback;
- using clear, specific instructions;
- addressing unacceptable behaviour regarding disabilities by others;
- creating alternative spaces.

4 WORKSHOP RESULTS

The terms used varied significantly between contexts, with those similar to ‘non visible’ including ‘non apparent’. Although use of the term neurodivergent was common, deficit terms such as “handicapped” and “slow” also featured. ‘SEND’ or ‘special educational needs and disabilities’ was used by one participant. Multiple participants said that terms were not discussed or disclosed and that the focus was on the accommodations. One participant said that students were referred to as ‘extra time students’ by both staff and peers.

Accommodations included extra time and rest breaks; flexibility of deadlines; provision of quiet, sensory, or resource rooms; eating in class; one to one tutoring; and online provision. One participant noted that reasonable accommodations were referred to as ‘excuses’ in their context.

Discussion of support within learning and teaching primarily focused on group work, presentations, and project-based learning. We discussed: the creation of plans for missed sessions; requests for private feedback; low stakes opportunities to present; transparent course structures; use of flexible deadline and grading policies; capturing spontaneous feedback electronically; use of alternative workspaces; scaffolding team agreements; and self-advocacy within groups.

It is clear that the terms and practices used within different contexts varies considerably and that deficit approaches are still common. It is therefore likely that the community would benefit from sharing practice.

5 SIGNIFICANCE AND CONCLUSION

Participants benefited from an increased awareness of the different contextual uses of the term NVD, as well as ideas about how to enhance the experience of students with NVDs in their own institutions. The workshop also contributed to the development of a safe space in which to discuss issues which had received relatively little prior attention within the SEFI community. It demonstrated enthusiasm for such work and has helped foster relationships between interested parties. This session therefore formed a basis for the formation of community of engineering educators interested in supporting the education of students with disabilities.

As facilitators of the workshop, we have two key reflections:

1. A large number of participants disclosed and shared their own personal circumstances with us, something which may be expected of a self-selecting audience. However, the openness to share may be an initial indication of the development of bottom-up movement towards challenging some of the embedded misconceptions and the status -quo.
2. A critical aspect going forward may be shortage of data and establishing ways of collecting it.

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