Pedagogic experiences in problem-based learning environment focused on human-centred design

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Keywords: Authentic Learning, Problem-based Learning, Pedagogy, Human-centred design

INTRODUCTION

Over the past three years, the Faculty of Engineering Science at University College London (UCL) has undertaken a critical review and reform of the curriculum for the majority of its undergraduate engineering programmes. This is in part due to an overwhelming sense of flux attributed to the state of engineering education within the United Kingdom. There is a wealth of reports reviewing and offering acute assessments of the suitability of engineering graduates for roles in industry with common themes being very well rehearsed. For example, "Universities must do more to ensure students acquire the generic transferable skills they will need in their future career – including communication skills, self management and business awareness – alongside the core academic content of university courses. The teaching of these skills should not be viewed as a discretionary 'add-on'" [1]. The pedagogy of problem-based learning will also help to support a key message echoed by the Royal Academy of Engineers, "University engineering courses must provide students with the range of knowledge and innovative problem-solving skills to work effectively in industry as well as motivating students to become engineers on graduation" [2].

Authentic learning practices can help provide educational opportunities to tackle many of the expressed shortcomings of higher education institutions. Lombardi explains that authentic learning typically focuses on real-world, complex problems and their solutions through the cultivation of 'portable skills' acquired through real-world, discipline-oriented applications. Her study goes on to exemplify ways "authentic learning intentionally brings into play multiple disciplines, multiple perspectives, ways of working, habits of mind and community", whilst putting the focus back on the learner [3]. Engineering in Society, an e-book written to give new students "some idea of what their future career might look like", furthers this argument by impressing on students that "your role as an engineer has to be understood in the context of your work within a company, and ultimately within society" [4]. McCarthy, one of the authors in this collaborative piece, goes on to explain “that engineers have a responsibility but also a great opportunity… to shape our world – physically, digitally, socially and economically”.

The reforms aimed to create a distinctive programme featuring a connected-curriculum and drawing on the excellent research-base of UCL. A founding premise was that although a strong disciplinary foundation was vital, modern engineering problems do not respect these disciplinary boundaries. Therefore, modern engineering graduates must be able to work in multi-disciplinary teams on interdisciplinary problems. They must have a strong basis in fundamental mathematics and engineering science, but must also have highly developed problem solving and communication skills. In addition, the modern engineer should understand the context of the problems they address, appreciating the ethical, societal and financial connotations of their design decisions. To yield such engineers, an integrated curriculum that develops all these areas simultaneously is required. Arguments lead by Jean Lave and Etienne Wenger that all aspiring scientists and engineers need to be ‘enculturated’ into the discipline as soon as possible in their education careers, also align with the ethos of the new programme [5]. Through this process students should also learn to “recognize whether a problem is an important problem, or a solution is an elegant solution, or even what constitutes a solution in the first place”; a schema John Seely Brown acknowledges as part of the ‘genres’ of the discipline [6].

The programme that resulted has been named the Integrated Engineering Programme (IEP) [7] and the first students to embark on this programme, a cohort of nearly 700, started in September 2014. Its most significant contributions are the embedded experiential and authentic learning opportunities, which provide students to apply their technical knowledge and develop their professional skills in various engineering design modules/activities year on year. The first opportunity for every student at UCL Engineering is within the cornerstone Integrated Engineering Design module. This paper seeks to share the apperception and evaluation of pedagogical experiences carried out during the first of two 5-week ‘Challenges’ that make up this year 1, term 1, multi-disciplinary problem/project-based learning (PBL/PjBL) [8] module, which focuses on human-centred design [9].

1 RESEARCH OBJECTIVE AND METHODOLOGY

1.1 Objective

The main objective of this research was to investigate the strategies, dynamics and results of efforts to support a key learning outcome for the new module – engaging students with the process of engineering design [10]. Furthermore, it aims to provide a critical review of the new interdisciplinary module, aptly referred to as IE Design or the Challenges, from the perspective of the enrolled students, via their individual feedback and reflections.

The Challenges module places engineering design at its core and aligns its pedagogic practice to the well-known and established principles of PBL/PjBL. This article presents a set of pedagogic experiences observed and analysed: contextual and enquiry–based learning with cultural partners and external advisors as part of the teaching team and regular formative assessment ‘Design Review’ meetings where students present progress made on collaborative research, ideation and documentation of the their design and project work. The students’ evaluation of these two fundamental module components has provided a rich data set, which has also assisted in formulating a sense of their individual and team achievements.

1.2 Methodology

The methods of conducting the research include the analysis of reflective writings by each student throughout the first of the two 5-week Challenges. This data is supplemented with student feedback, which has been provided during follow up interviews and focus groups. Presented first, however, is statistical data generated from two student surveys which helped to provide an understanding of the students learning expectations upon arriving at UCL Engineering and the learning outcomes achieved after having completed the module.

2 IEP IMPACT STUDY: ESTABLISHING THE STUDENT VOICE

A longitudinal study is currently being established to look at the impact of the programme on students enrolled in the Integrated Engineering Programme (IEP) at University College London. An important piece of evidence for the IEP impact study is a short on-line survey completed by the newly enrolled year 1 students at the beginning of their first term at UCL, prior to the start of classes. The primary purpose of the survey was to understand the initial perceptions of the students upon embarking on their engineering education at UCL. Moreover, the results are currently being used to guide improvements in the programme, as well discipline specific, curricular design. The survey was also designed so that it could be completed by the IEP students at the start of each academic year throughout their degree. The motivation is to understand if any changes have occurred in the student perception of their educational experiences throughout their chosen degree and the IEP.

The first set of questions in the survey, which have been included in this paper, asked the students to ascertain future opportunities they seek as engineering graduates. The participants were then asked to consider their own learning expectations and to anticipate the most enjoyable as well as beneficial educational experiences. The following section set out a series of statements to understand the student's intentions for choosing UCL as their educational institution and reasons for choosing to study engineering whilst the final section poses a single question asking the students to reflect on their confidence levels on a series of skills, which are considered as essential to anyone pursuing a career in engineering.

Initial findings suggest that upon graduation nearly a quarter of the UCL Engineering IEP cohort is seeking a career that suit them personally and provide a sense of happiness. Moreover, ten percent of students would like to positively contribute to the world around them. An innate sense of continuous learning and civic consideration in the role of an engineer has also been relayed by ten percent of the students, as they seek opportunities to expand their own knowledge, skills and attitudes in engineering and beyond. A separate ten percent of the cohort is driven by the intrigue, excitement and challenges that are associated with working on real-world engineering projects.

The opportunities sought after by first year UCL engineering students are supported by the learning expectations they have communicated for their time spent as undergraduates. Building technical knowledge of their chosen discipline and solving real engineering problems appear to be the most significant. Ten percent of students expect to learn how to 'think' like an engineer, build knowledge and collect information for their future career and improve communication, presentation and technical writing skills. The results of the survey convey prevalence for these three areas over their expectancy to improve individual team-working skills, mathematic and science knowledge, design and making skills and creativity. Students also believe these to be more important than achieving a top grade.

Results of the questions seeking the student's opinion on the most beneficial and then separately, the most enjoyable education experiences in their development as a professional engineer, support the changes brought on by the IEP. The results in Table 1 give insight into the educational experiences that the students perceive will be most beneficial. In the column on the right, the most enjoyable experiences as anticipated by the students surveyed, are also provided.

A simple deduction that could be drawn from the results of the student survey is the high value and expectation they have in regards to the perceived benefits and enjoyment of 'authentic educational experiences', 'exploring team-based problem solving opportunities' and 'developing individual professional skills'. Even before their first class, students are of the opinion that 'lectures', where the conveying of technical information and content occurs between academic staff and a passive student audience, will be beneficial to their own development but not necessarily enjoyable. The 'independent learning' experience has gathered a similar impression. Interestingly, 'engineering labs' and 'learning from fellow students' are viewed by those surveyed as being enjoyable but rather less beneficial. The results even suggest that students feel as though 'engineering labs' would be more enjoyable than the 'authentic engineering experiences' supported by industry and community involvement. From this, it is evident that the students will enjoy the hands-on experience that comes with working on engineering projects. The authenticity in this style of learning is something that the Integrated Engineering Design module hopes to appropriate and assimilate to the engineering 'Challenges' that comprise its syllabus. As the module is augmented by industry and community involvement, the provision for students to benefit and experience enjoyment whilst participating in the presented authentic engineering opportunities can be realised. Furthermore, the enjoyment that comes with learning from fellow students is reported as higher than the perceived benefits. Because this cornerstone module of the IEP is rooted in principles of team-based learning, impetus to help increase the student's perception on the value of learning from their student colleagues is emphatically provided.

Table 1. Impact Survey Year 1 Data

Pedagogical Experience	Most Beneficial (%)	Most Enjoyable (%)
Engineering team-based problem solving	26	24
Authentic engineering industry and community experiences	19	19
Activities and experiences to develop professional skills (e.g. leadership, team-working, communication)	18	17
Lectures taught by academic staff	12	5
Engineering labs	11	21
Independent learning	8	5
Learning from fellow students	4	8
Revising for and sitting exams	2	1

3 INTEGRATED ENGINEERING DESIGN: UCL ENGINEERING'S CORNERSTONE DESIGN MODULE

The IE Design module is intended to give the students an opportunity to put their learning into practice by working in an interdisciplinary, problem/project-based learning, industry linked and design focused environment. At its core, is the deliberate attempt to make use of and explore the creative and stimulating aspects of human-centred design as practiced by 'real' engineers and computer scientists in industry. This is highly supplemented by embedding the exploration and use of professional skills needed to be successful in the enticing and highly competitive working world. In many ways the insights, presented by the voice of the students through the initial IEP Impact survey, give evidence to many of the empirical reasons for introducing radical changes to the undergraduate curriculum. None more so then the strategic scheduling of a team based, multidisciplinary, design focused PBL/PjBL module from the first day of classes.

The basic structure of the first term IE Design module consists of two 5-week 'Challenges', which have the students working in teams of mixed cohorts. The themes for the ill-defined problems for the two Challenges are linked to such global challenges as sustainability and health. The learning objectives of the second Challenge build from those of the first. The first has its basis in problem-based learning, whilst the second has a higher level of specification that aligns well with the principles of project-based learning [8]. The technical focus and level of difficulty also increases from the first to the second as the students in the first 5-weeks of term are considered to be bright, inquisitive, enthusiastic, high-achieving students well versed in STEM subjects, but who do not have much technical knowledge of their chosen engineering discipline. Upon completion of the IE Design module, an initial sense of autonomy in the students is expected as they take responsibility for your own learning through your individual and team based experiences.

Both Challenges are presented to the teams of students with a human-centred design approach to problem solving in order for them to take into consideration stakeholder and user needs [9]. Students are positioned to experience and understand what it feels like for actual stakeholders beyond the classroom to hold them accountable for their work products and this is achieved by including external community groups, cultural and industry partners as holders of the Challenges presented to the students. Students are implored to identify and define the requirements, constraints and design parameters of their project, whilst engaging in research-led activities and self-study through enquiry-based learning. They are taught to explore the iterative processes of design and engineering thinking, whilst applying mathematics and engineering analysis to the development and creation of an integrated engineering solution. There is a focus in the first Challenge on the use of creativity to generate concepts, exercise critical thinking, implement a methodology to compare ideas and use engineering judgment to choose a final solution. Whereas, the second Challenge affords the student an opportunity to demonstrate knowledge and understanding of the equipment, materials and processes employed in the design, production and testing of integrated engineering systems, including specialized test and measurement equipment relevant to your chosen engineering discipline. Assessment of the students project work varies between the two Challenges as well, with the first asking the students to keep a reflective journal and e-portfolio before showcasing and technically arguing their team solution in a video and the second calling for student teams to model, build and test working prototypes with relatively smaller presentation and writing components. The module and the associate Challenges are supported through the integrated and aligned syllabuses of the three other term 1 modules, which the students are concurrently enrolled. These modules comprise Mathematical Modelling and Analysis, Design and Professional Skills and a technical introduction specific to their chosen discipline.

Results of the evaluation survey for the IE Design module, completed by the students at the end of the term, indicated that all of the intended learning outcomes were successfully achieved by 50% of the cohort. This is considered a fair result, however improvements can be made. More pleasing, perhaps, is the relatively high percentage of students who acknowledged their learning to:

- Take responsibility for your own learning experience (72%);
- Work effectively in a team (68%);
- Engage in research activities and self-study through asking questions and general inquiry (67%); and
- Apply a human-centred design approach to problem solving by considering stakeholders and users needs (62%).

4 PBL PEDAGOGICAL EXPERIENCES VIA STUDENT REFLECTIONS

The following section of this paper sets out to evaluate two key pedagogical experiences within the first of the two 5-week Challenges. A short description is provided along with student feedback collected either in person, via email / Moodle (i.e. online module intranet) discussion boards or as posted in individual e-portfolio reflective writing coursework. Following each is an attempt to share the observations and reflections associated with each, whilst attempting to formulate a sense of achievement on their behalf but also in terms of the module aims.

4.1 Contextual and enquiry-based learning of the design process with cultural partners and external advisors

A top goal of the IEP is to have UCL Engineering graduates move on from their time in higher education skilled with the ability to take on a problem, navigate their way through a process of design and generate a solution that is efficacious for all stakeholders involved. The iterative process of design requires continuous questioning and resilience on the part of the design team. Introducing cultural partners within the teaching team and technical experts as external advisors has opened up opportunities to embed contextual and enquiry-based learning within the PBL environment of the first Challenge. The overarching problem set within the Challenge was based around Sustainable Energy and the cohort was split into ten smaller working groups, which represented various countries around the world. This format created an opportunity to include cultural context into the Challenge as academics from across the university and cultural community leaders from across London and abroad were brought in as teachers to enrich the student experience with an increased level of authenticity. External advisors were also brought in at strategic times within the 5 weeks to advise the students on technical and specialised topics regarding sustainability and energy. The additional members of the teaching team provided hours of facilitation both in the classroom as well as virtually in online forums as well as additional teaching and research material, however, the interaction between the students and the cultural partners / external advisors was student led and guided by the shared knowledge of the design process.

Student Reflection – Example #1: "*Our initial step was to research into what the actual problem is. We investigated and researched further into the problem to find out about all aspects of the energy problem. We looked at all aspects of the problem, not just the technical bits, and then started to think about some good and viable solutions for the problem. The research helped us come up with ideas. The research was tough though, sometimes I had no idea what I was reading or what was I asked the external advisors, but we had many study sessions together as team and meetings to brainstorm ideas and then we started coming up with some real diverse solutions.*"

Student Reflection – Example #2: "*The most dominant professional skill that we used, was in-depth research in our topic. All of us researched a lot. We started* *asking a lot of questions to the energy experts. I am good at asking questions! We had a big variety of ideas and possible solutions to each design, which was interesting to discuss. The other important skill was that of presentation by which we made our solution understandable by our teachers, classmates, advisors and community partners.*"

Student Reflection – Example #3: "*I have learnt that the design process is a useful tool to use on projects as it helps you get organized for the project and increases your chances of success. The research we had to do, particularly at the start, was fun because we got to ask questions to our advisor living in Peru. He helped us understand what it is like living in a small rural and energy poor village on the coast. It felt more real getting information from him than on the internet."*

The focus on the process of design and a clear intention to have the students explore what engineering thinking is through enquiry has helped to give them a sense of self-efficacy. As relayed by the student in the Example 1, understanding (even briefly) the stages in the design process has helped many teams get through the first 5-week Challenge successfully. Because the process itself is often iterative by nature, which may require the need to question, rethink and restart the work that has already been completed, it can often be frustrating. The frustration is often amplified when working in a team. Giving the students a sense of organization and resilience through the creative process is something that many appreciated.

Many would attest to the stereotypical portrayal of engineers who often skip the creative thinking or ideation phase of the design process and start at the testing and implementation of their first idea. Accordingly, engineering students are seemingly no different. Feedback from academic and industry advisors have indicated that students struggle with affording themselves enough time to properly investigate and research the problem, the stakeholders and their needs as well as the state of the art that currently exists in their technical fields. The first of the two Challenges, forced the students to complete an exhaustive research and self-study of the cultural and technical challenges surrounding their assigned country, the people that experience the problem and the policies, strategies and technologies currently available. The student reflections in Example 2 and 3 have also touched on how time dedicated to self-study after much interaction with community leaders and external advisors in has contributed to the quality and quantity of ideas generated by the team. The authenticity of both the real life problem and the engineering project compel the students to further their own learning, which often results in a greater engagement with the problem and the stakeholders involved.

4.2 Regular formative assessment 'Design Review Meetings'

At two timely milestones within the 5-week Challenge, meetings were scheduled between each of the student teams and their academic leader. The meetings occurred informally during the workshops, where the academic leader would move around from team to team in the two-hour regularly scheduled timeslot, sitting and conversing with the students. Students were given guidance notes ahead of the meetings, in order for them to understand how they were meant to prepare for the meeting and what work needed to be completed in advance. The meetings themselves were set out in a working-life setting, which engineers are often called upon by a director or an external client to disclose details of their project work as well as an update on progress. Students were asked to prepare and deliver a short presentation summarizing their work at the start of the meeting and then, the academic would follow up with their feedback and questions. An expectation was set up with the students that they were to lead the meeting and that they should make the most of the meeting with the academic to clarify any misunderstandings or uncertainties they were encountering.

Student Feedback – Example #4: “*The following are the lessons I learned from our meeting with our academic leader:*

- *To not give information we cannot back up will facts and correct statistics.*
- *We need to do more research into the stakeholders (people affected by this project e.g. miming companies) of this project and how are they affected.*
- *We need to understand what sustainability is properly.*
- *Our arguments need to be more technical and very detailed.*
- *We need to find out answers to some very detailed questions like, 'How much do these people earn?' and 'How much energy is used in schools, by females, males and children?'.*
- *If we don't know something we should not assume but be honest and say that 'we do not know etc.... and we need to find out'*.”

These meetings also served as a means of encouraging an ipsative learning environment [11], in which both the students and academics could engage. Many students feel a real sense of achievement when progress is acknowledged and these meetings gave academics an opportunity to provide that for their students. Interim coursework deadlines associated with these meetings also supported the students in their own time management. The weekly deadlines associated with the meetings and the individual components of the project work wasn’t appreciated by the students as many regarded the anxiety and pressure to deliver work as too overwhelming in their first 5-weeks at UCL. This was quickly dismissed when students realised that much of the work had been completed in advance of their final submission deadline before the half term break. It is important to note that the schedule for submission of work is not as controlled in the second Challenge, giving the students a varying approach to time management of both individual and team elements of coursework. This was a strategic design of the module syllabus, as it was felt that autonomy of ones own learning can only be realised if given a variety of experiences to explore and evaluate.

The content of the student reflection lends support to the notion that in PBL, facilitation can help the students to explore their research and go into further depth with their ideas and concepts than if left without. Often the facilitator will expect the student to formulate an opinion, gather evidence to provide a technical argument and make decisions on matters that perhaps they would not have, if not challenged to do so. Lastly, it is important that the students understand that failure can be beneficial to their learning experience. Often this realization doesn’t occur unless the academic reassures them and guides them through it. The realization made by the student that he/she cannot make assumptions without finding evidence to support it, is an important one. It isn’t until students are faced with having to explain their own logic, estimations and assumptions that they come to realise the importance of this.

5 SUMMARY

This paper gives a brief overview of a major element of the year 1 Integrated Engineering Programme, a revamped undergraduate curriculum review project at UCL. The aim of the IE Design module is to enhance the student experience by introducing problem/project-based activities that allow students to put the basis for engineering design and thinking into context and practice. This is primarily done through team-based learning. It draws on the broad research base of UCL to create a connected-curriculum with a number of multi-disciplinary elements to students entering their first year. Individual reflections and feedback from the students who have recently embarked on the programme have served to give a real sense of their personal achievement. Analysis of the data collected has shown that the pedagogic experiences embedded into the first 5 week Challenge are successful in initiating student learning for how to conduct research, whilst compelling their active participation and independent critical investigation of the design process. The authenticity, level of detail and cultural diversity associated with the context surrounding the human-centred problems given to the students as design 'Challenge' are thought to be, in many ways, the main catalysts to the students' level of engagement.

These outcomes have been shared with the teaching team, as well as academic staff across the faculty and then used as a means to evaluate the achievements of the cornerstone module. The data collected have helped to inform improvements to the module for future years, whilst highlighting a group of students who are keen to support future developments.

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