Professional Formation of Engineers:

Enhancing the First Year Student Experience

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INTRODUCTION

Social cognitive career theory posits that greater knowledge of occupation specialities and greater match between one's image of a career and one's self-identity are each associated with greater confidence in career choice [1]. Similarly low engineering enrolments are attributed to "poor experiences of science and engineering education among students generally, coupled with a negative image of and inadequate information about, careers arising from the study of science and engineering" [2]. While there are misconceptions as to what engineers actually do [3-5] engineering is also challenged "to prevail in an intensively competitive market where a wide array of non-technical factors determine success" and where technological performance has become invisible; engineering primarily involves the computer screen and "direct hands-on technology experience is nearly impossible in the everyday environment; thus, eliminating a strong incentive for pursuing it" [6]. It is asserted that neither the engineering profession nor the educational system supporting it has kept pace with the changing nature of the "knowledge-intensive society and the global marketplace" [7].

Lack of knowledge about engineering practice not only impacts on students' transition from school to engineering education but also on students' transition into engineering practice. There is a further impact on undergraduate learning; social cognitive expectancy-value theory posits that engineering students with heightened interest in professional practice will demonstrate more cognitive engagement [8-10]. At the same time the technical and mathematical sciences on which engineering courses are built often do not explain the landscape of practice [11] and first year engineering students in particulardo not see the big picture surrounding technically focused courses and how they relate to "real" engineering. Consequently "many of the engineering students who make it to graduation enter the workforce ill-equipped for the complex interactions, across many disciplines, of real-world engineered systems"[12]. Building a deep understanding of engineering practice into the curriculum has the potential to greatly strengthen engineering education [13].

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This paper reports on a study investigating engineering students' perceptions of engineering practice and whether engineering students' cognitive engagement benefits from bridging the gap between the technical issues in their education and the practical realities of modern engineering practice.

1 METHODOLOGY

There are four parts to this study: (i) an exploration of engineering students' perceptions of their preparation for professional work; (ii) design of engineering practice portfolio to inform students about engineering practice; (iii) an investigation of the impact of the portfolio on first year electronic engineering students' learning and (iv) determination if the portfolio provides any long-term learning benefits.

1.1 A mixed methods approach is employed to investigate students' perceived usefulness of engineering education in the context of future careers as practising engineers. Electronic engineering students at the Institute of Technology Tallaght Dublin rate the importance of professional engineering competencies and also the degree the students have developed these competencies. The list of competencies is developed based on (i) attributes of a global engineer [14] and (ii) mathematics usage in engineering practice [15]. Students' perceptions of their preparation for engineering practice are explored qualitatively.

1.2 The portfolio of engineering practice, developed for this study, presents four different perspectives of engineering practice: (a) the landscape of engineering practice [16]; (b) Engineers Ireland education standards [17]; (c) industry examples of Engineers Ireland education standards and (d) practising engineers' stories about their education and work.

1.3 A mixed methods approach is used to capture first year electronic engineering students' perceived value of their engineering education and their feelings about their future careers before and after learning about professional practice at the end of semester one. Students' examples of real-world practicality skills and students' examples of Engineers Ireland education standards are captured both before and after the portfolio learning experience.

1.4 Focus groups are used to explore the impact of the portfolio of professional practice on first year students' long-term learning. The focus groups capture students' account of the portfolio influence on their semester two learning.

2 RESULTS

2.1 Students' learning is based solely on the academic viewpoint

While students are motived to study electronic engineering to get a job as professional engineers, students show no evidence of expected career paths. There is an assumption that engineering education is matched with professional engineers' skills requirements. There is also a belief that good examination performance underlies good professional performance. However students have a strong belief that practising engineers require an understanding of engineering, science, and mathematics fundamentals, an ability to think both individually and cooperatively and effective functioning on a team. Fluency in at least 2 languages, non-mathematical ideas and speed of calculations are considered significantly less important. Gaps between competencies required for engineering practice and competencies learned include: international/global practice; professional competence; ability to think both individually and cooperatively; understanding of ethical and business norms and ability to think both critically and creatively. The dominance of the applied engineering sciences at the expense of tacit knowledge, political, social and economic perspectives an ability to achieve practical results through other people is noticeably lacking in the students' engineering education[18].

2.2 The portfolio of engineering practice

The landscape of engineering practice as described by James Trevelyan (2014) describes what engineers actually do at work. While technical expertise distinguishes engineers as an occupational group, socio-technical factors shape the landscape of practice. Engineering, while often associated with engineering products, is actually human performance. An engineers' job is to provide value e.g. economic value, social justice, sustainability, safety, protecting the environment, security, defence etc. Engineering is not a hands-on practical occupation, neither are engineers naturally concise and logical and neither do they work with objective facts. Instead engineers have to work with missing and uncertain information and most engineering design is based on precedent as there is never enough time to investigate everything. Engineering is much more than design and problem solving; engineers spend about 60% of their time interacting with other people and computers do the mathematics. An engineering project is specified by client requirements, standards, regulations, social needs and environmental constraints and it has a project life cycle. Engineers need to know it all: the engineering enterprise, explicit knowledge, procedural knowledge, implicit knowledge, tacit knowledge, contextual knowledge, engineering knowledge and technical knowledge in the workplace [16].

Engineers Ireland education standards comprise seven standards that engineering education should deliver competence: (A) mathematics, engineering sciences and technologies; (B) complex engineering problems; (C) system design and data analysis; (D) experiments (E) ethical standards (F) individual, team and multidisciplinary settings and lifelong learning and (G) communication [17].

Industry examples of Engineers Ireland education standards are provided by EirGrid plc, the independent electricity transmission system operator in Ireland and the market operator in the wholesale electricity trading system [19], one example is illustrated in Figure 1.

Practising engineers' stories include real engineers' education experiences, their career decisions and accounts of everyday professional engineering work. The stories were compiled following interviews with a sample of twenty professional engineers practising in Ireland [20]. A snapshot of one engineer's story is illustrated in Figure 2.

e) An understanding of the need for high ethical standards in the practice of engineering, including the responsibilities of the engineering professions towards people and the environment.

Grid Development

In order to implement Government policy and keep the current standard supply of electricity provision, we need to develop the transmission system which includes developing key infrastructural projects. In order to build these projects with the least impact possible, we produce constraint maps incorporating various constraints for example cultural heritage, ecology, geology, hydrology, population etc. We then engage and consult with affected stakeholders on projects, for example agriculture, tourism and equine stakeholders, to determine the best possible route and/or location for the project.

Operating the Market

The Single Electricity Market is a market facilitating the provision of electricity to approximately 2.5 million electricity consumers, to Northern Ireland and the Republic of Ireland in sterling and euros, respectively. The aim of the market is to ensure that power producers are remunerated for providing power but that the consumers are exposed to the lowest price possible, while remaining cognisant of the fuel types, safety and environmental impact of the electricity system.

Ecology Guidelines for Electricity Transmission
http://www.eirgrid.com/media/Ecology%20Guidelines%20for%20Electricity%20Transmission%20Projects.pdf

Community Update
http://www.eirgrid.com/media/North%20South%20400%20kV%20Community%20Update%20Brochure.pdf

Figure 1 Example of Engineering Practice Aligned to Engineers Ireland Standards

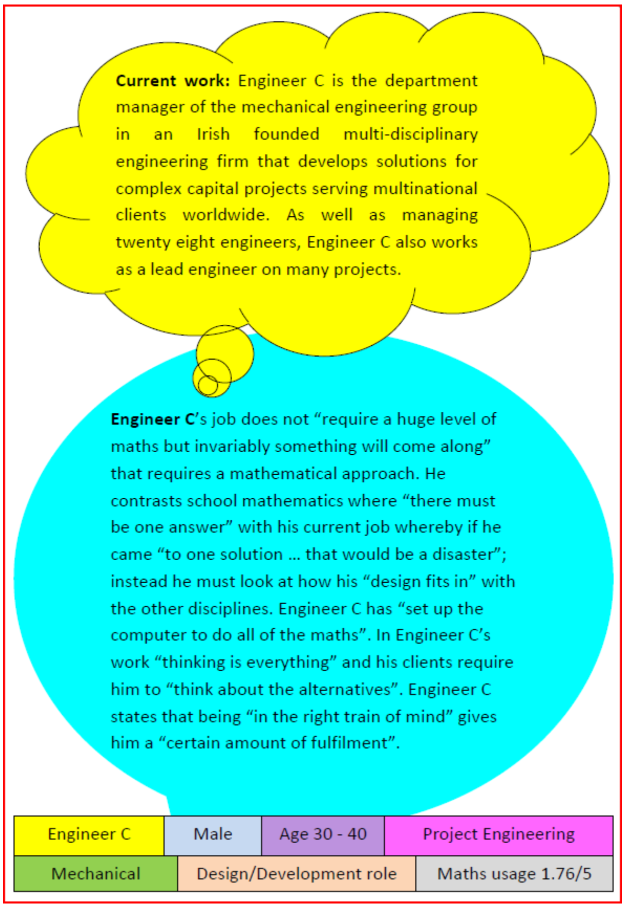

Figure 2Example of a Practising Professional Engineer's Story

2.3 The portfolio increases students' engagement with and value of engineering education

Before the portfolio learning students perceive their course as useful preparation for work but they are unable to give any supporting reasons. Students' examples of real-world practicality skills are based on their engineering education thus far, for example "*soldering*" and "*build digital timer circuit.*" Students are unable to provide examples of Engineers Ireland education standards. While students' high value of mathematics, before the portfolio learning, is apparent, this has reduced significantly after the portfolio, because students "*learned that the technical side of engineering i.e. mathematics, did not dominate the daily lives of engineers.*"

The impact of the portfolio on student motivation is illustrated in the following student statement: "*I know now where I could be heading and I know the process of getting there.*" Other benefits include: "*I think it was an eye opener on engineering, what to expect and what to prepare yourself for,*" "*it gave me a great insight into what engineering fields my skills could be applied and what an engineers' job is*," "*common sense is important,*" "*the survey with past and present engineers was particularly helpful,*" and "*there isn't ever just one way to solve a problem, but many ways.*"

The portfolio increases students' learning engagement: "*I will start to focus on what I am learning and consider how I would use it in the workplace,*" "*I would probably focus more on organisation and communication skills in the future because they were outlined as important*," "*I will probably think back to this when covering specific topics in class*", "*I feel the portfolio will help me to think outside the box, I should also be looking at things we are not covering in college,*" and "*I have a greater respect now for what is being taught and will not take it for granted.*"

Another significant outcome is students increased value of engineering: "*I learnt how big and important engineering is.*" The impact on career choice is also evident: "*before the portfolio, I didn't really know exactly what engineering is and how my skills would apply later on*" and "*this would help students really know if they want to pursue engineering*" [21].

2.4 While knowledge of engineering practice gives students a new appreciation of engineering education and teaches students to reflect on the workplace value of academic tasks, students' learning should be supported by knowledge of how their course relates to the workplace

While students showed great awareness of the differences between engineering education and practice, they showed a new appreciation of their engineering education. One semester after the portfolio learning students illustrated how the portfolio had changed their approach to learning: "*I used to work by myself but I started working with my classmates, helping them and they helping me*;" "*last semester I had a fear of practical work, now I communicate more within the group and this makes it easier*;" "*I sometimes think about how the equipment in the laboratory is used in the real world or if the workplace had more modern equipment*;" "*I can now relate the lab [laboratory] work to what I will be doing in the future,*" "*I couldn't relate first semester maths to anything but in second semester I can see how basic maths can be used in engineering and this makes it more interesting to study*" and "*nobody likes writing reports but it is important for engineers to explain what you're doing so your boss will understand your work*."

Students demonstrate that their approach to learning is not only motivated by "*learning just to pass the exam*" but also by questioning the "*value of topics in the workplace*." While students initially "*didn't realise that computers did so much for you,*" they subsequently felt "*inadequate*" and "*cheated*" when they learned that the effort expended by "*hours of hard work*" and "*getting it wrong*" could be replaced by "*seconds on the computer*." Students say that the portfolio taught them to reflect on the workplace value of academic tasks and that "*computers doing all the mundane jobs*" was actually a source of "*huge relief*"; students learned that their learning value was not so much "*manual effort doing routine stuff*" but rather the "*bigger value of understanding how stuff work*s."

Students indicated that their preparation for engineering practice was a learning journey that would continue into their working life. They were starting off with a "*broad education*" that would lead them towards a more "*specific role*" in engineering practice. In particular students stated that they needed a broad learning because they were to become "*more than a user*," and they needed "*to understand the [engineering] process*." However students were adamant that they "*need to know why you need to know it.*" Students say that unlike secondary school where they questioned "*why do I have to do this*", in third level there was an "*expectation*" that their "*course has something to do with what you want to do afterwards*." Students sought assurance in the form of support that "*relates the course to the workplace*" and thus "*inspire you to focus more on what you're doing in class*." On top of that students say that instead of "*enduring hardship for four years*" they need to feel "*good about their co*urse." Students suggested that "*an hour each month relating course to workplace would inspire you to focus on what you are doing in clas*s."

3 CONCLUSIONS

While engineering students' ultimate goal is to get a job in engineering practice, they have no clear picture of what engineers actually do; students' values and beliefs about engineering are based solely on their coursework and on the academic viewpoint. This corresponds with the research literature wherein engineering is described as a diffuse professional field because students have "*unclear expectations about their transition from study to working life*" [18, 22].

As well as addressing the mismatch between engineering education and practice, this study has implications for engineering career choice; the portfolio insight into engineering practice illustrates "*how big and important engineering is*."

The portfolio of engineering practice introduces students to real engineers' work; students show particular interest in the real engineers' stories part of the portfolio [20]. The immediate benefits of the portfolio include students' increased expectancy, value, goals and schemas and affective memories. The importance of value (why should I do a task?) as a predictor of student achievement behaviour is evident; students who value and are interested in engineering practice are more likely to choose tasks, they believe are important in engineering practice, in the future. Students' goals are to work in engineering practice; goal setting is a key motivational process and learners with a goal and a sense of self-efficacy for attaining engage in activities they believe will lead to attainment. Students develop positive emotional responses to the portfolio learning; students, who initially felt *"inadequate"* and "*cheated*" by "*hours of hard work*" and "*getting it wrong*", now have a feeling of "*huge relief*"[10].

It is concluded that teaching students to reflect on the workplace value of academic tasks greatly enhances learning; according to the first year engineering students, there is a *"need to know why you need to know it."*

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