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***Abstract**: A common theme in the scholarly literature describing engineering is associated with the conception of the term global engineer where the role of the engineer has become quite broad. This study investigates engineering students' perceptions of their future careers and their preparation for professional practice. This is important information for engineering educators as students with heightened interest in professional practice demonstrate more cognitive engagement. Additionally many graduate engineers are challenged by the transition into engineering practice. A mixed methods approach is employed. The degree competencies are required and learned by electronic engineering students, at the Institute of Technology Tallaght Dublin, is investigated statistically. Students' perceptions of their future careers are explored qualitatively. The results show that students' learning is based solely on the academic viewpoint. Gaps between competencies required for engineering practice and competencies learned are identified. It is concluded that there is a need to make professional engineering clearer.*

Introduction

Preparing engineering students for professional practice is a major challenge for engineering educators. Modern engineering practice includes "complex social, physical, and information interconnections" (Sheppard, Macatangay, Colby, & Sullivan, 2009). Often the technical and mathematical sciences on which engineering courses are built do not explain the landscape of practice (Trevelyan, 2013) and engineering students do not see the big picture surrounding technically focused courses and how they relate to "real" engineering. Adjusting to the workforce can be problematic for many engineering graduates as they discover what they learned at university needs to be contextualised for work (Wood, 2010). A challenge for many new engineers is the accuracy of their methods; while engineering students learn to devise solutions that are based on data, many real world engineers often rely on precedent and other people's judgement (Korte, Sheppard, & Jordan, 2008).

Lack of knowledge about engineering practice not only impacts on students' transition from education into engineering practice but also on undergraduate learning; social cognitive expectancy-value theory posits that engineering students with heightened interest in professional practice will demonstrate more cognitive engagement (Schunk, Pintrich, & Meece, 2010; Wigfield & Eccles, 2000; Wigfield & Eccles, 2002). Similarly in a clear field, where the nature of the profession is obvious, professional requirements can direct the course of learning. When a professional field is diffuse, professional roles and expectations are not obvious and students have unclear expectations about their transition from study to working life (Reid & Petocz, 2013).

This study explores students' perceived usefulness of engineering education in the context of their future careers as practising engineers. Knowledge of students' perceptions provides educators with important information that informs curriculum design, teaching methods and preparation for professional practice. The study is motivated by the reported disconnect between engineering education, the concept of a Global Engineer and practising engineers' mathematics requirements.

The disconnect between engineering education and engineering practice

It is asserted that general engineering education is “attempting to educate 21st-century engineers with a 20th-century curriculum” (Duderstadt, 2008) and that “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” (Wulf & Fisher, 2002). While students’ perceptions of mathematics in their future profession influence their approach towards learning mathematics in university (Petocz & Reid, 2006), for many students, the nature of a career involving mathematics is not at all clear (Petocz et al., 2007; Wood, 2008; Wood et al., 2011). Newly hired engineers say that “workplace problems often lacked data and were more complex and ambiguous with far more variables” compared to school problems. They did not understand the big picture and interpreting data was a new experience (Korte, et al., 2008). Graduate engineers often struggle with the “open-endness” of practical design processes, where a multiplicity of possible solutions contrasts with “a single correct answer” that is generally assumed in undergraduate engineering education (Winkelman, 2009). There is a view that social issues such as communications and team work contribute significantly to the gap between engineering education and engineering practice (Tang & Trevelyan, 2009). A study of engineers who had been practising for no more than ten years, reveals the strong need for integrating “managerial, leadership, teamwork, creativity and innovation skills, as well as knowledge of business policies in classroom activities” into engineering education (Baytiyeh & Naja, 2010).

It is advocated that engineering education should be centered on professional practice and the “demands on the new-century engineer” (Sheppard, et al., 2009) and that building a deep understanding of engineering practice into the curriculum has the potential to greatly strengthen it (Trevelyan, 2010a). Engineering education is challenged to not only provide the technical expertise that distinguishes engineers as an occupational group but also by practising 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. At the same time engineering is human performance and engineers provide value e.g. economic value, social justice, sustainability, safety, protecting the environment, security, defence etc. (Trevelyan, 2014).

Global engineering

There is both an inadequate body of work on engineering practice and misconceptions as to what engineers actually do (Anderson, Courter, McGlamery, Nathans-Kelly, & Nicometo, 2010; Cunningham, Lachapelle, & Lindgren-Streicher, 2005; Tilli & Trevelyan, 2008). Students and second level school teachers generally lack an understanding of what engineers do (Courter & Anderson, 2009; National Academy of Engineering, 2008). Third level engineering schools have a “tradition of putting theory before practice and the effort to cover technical knowledge comprehensively, allows little opportunity for students to have the kind of deep learning experiences that mirror professional practice and problem solving” (Sheppard, et al., 2009).

The conception of the term Global Engineer indicates that the role of the modern engineer has become quite broad (Chatterjee, 2005; Lohmann, Rollins, & Hoey, 2006) Accordingly there are a number of different perspectives on what engineering practice is: it is “design process” (Eckert et al., 2004) “engineering practice is … problem solving” (Sheppard, et al., 2009); “the application of the theory and principles of science and mathematics to research and develop economical solutions to technical problems… the link between perceived social needs and commercial applications” (U.S. Department of Labor website, 2010-11); and “a decision-making process (ABET Engineering Accreditation Commission, 2010). It is also a societal activity focused on connecting pieces of knowledge and technology to synthesise new products, systems, and sciences of high quality with respect to environmental fragility" (Bordogna, 1992).

While engineering identity is a complex equation of problem solving, teamwork, lifelong learning and personal contributions (Anderson, et al., 2010) there is a view that engineering practice worldwide is changing. Many of the studies of engineering practice focus on the social relationships within engineering (Crawley, Malmqvist, Östlund, & Brodeur, 2007; Sheppard, et al., 2009). Research illustrates that engineering "relies on harnessing the knowledge, expertise and skills carried by many people, much of it implicit and unwritten knowledge" (Trevelyan, 2010b). Additionally engineering performance is time, information and resource constrained. Seldom is there complete information available and the available information has some level of uncertainty (Trevelyan, 2010a).

Practising engineers' mathematics requirements

There is a strong view that the engineering curriculum is overcrowded and that engineers should no longer be taught mathematics as if they were mathematicians (Lesh & English, 2005; Manseur, Ieta, & Manseur, 2010) . Graduates have to change their ideas of working with mathematics as it is used in the real world. For example, problem solving does not always require first principles; "combining approaches and partial solutions and applying them to the problem in hand" is preferred. Similarly engineering tools are widely used to solve real-world problems (Grimson, 2002) and engineers should understand the "mathematics and scientific fundamentals behind the software tools and techniques" (King, 2008). Practising engineers rely on mathematics-oriented critical thinking skills in addition to modelling, data analysis, statistics and risk assessment (National Academy of Engineering, 2005). They are required to be increasingly critical in "discerning information and making decisive judgments when confronting unexpected situations and novel problems" (Radzi, Abu, & Mohamad, 2009). However research shows that graduates are unable to communicate mathematically (Wood, 2010).

Methodology

This study sets out to explore students' perceptions of engineering practice and to investigate students' perceived usefulness of engineering education in the context of their future careers as practising engineers. A mixed methods approach is employed; data is collected using a survey with both quantitative and qualitative questions. A mixed methods approach provides both measurements and details of students' perceptions of the relevance of their learning.

Study Population

The study population is 177 full-time electronic engineering students at the Institute of Technology Tallaght Dublin (ITTD) of whom 90 participated in the study; this comprises of 15 year 1, 27 year 2, 12 year 3, 17 final year (years 4 & 5) students (mostly Irish students with a significant mix of foreign nationals living in Ireland) and 19 students who have transferred from Nanjing University in China to complete their final year at the ITTD. A student population is chosen to explore the student perspective of undergraduate engineering education and to explore students' understanding of engineering practice as developed in their education. Practising engineers are not included in the population as memories of their engineering education are likely to be distorted due to their work experiences. The sample size of 90 students is sufficient to within 0.3 Likert units with 95% confidence for estimation of the statistical mean (Reilly, 2006). The study participants were chosen at random; all electronic engineering students at ITTD were given an opportunity to participate in the study.

Survey Instrument

A survey questionnaire is chosen because (i) the electronic engineering student population in ITTD is diverse in terms of nationality and academic achievement (ii) there are a variety of pathways to achieving a level 8 (Honours Bachelor degree) qualification in ITTD; students can progress to level 8 via either level 6 or level 7 and (iii) there is no prior measurement of students' perceived usefulness of engineering education in ITTD. Electronic engineering education at ITTD comprises theory, practical laboratory work and a major project in final year of each of level 6, 7 and 8 awards. There is no structured work placement with engineering firms.

Using a five point Likert scale (1 = Not at all; 2 = Very little; 3 = A little; 4 = Quite a lot; and 5 = A very great deal), students are required to rate competencies and characteristics, they believe practising professional engineers require and also the degree they have developed these competencies. The list of competencies and characteristics required by practising professional engineers is developed based on (i) attributes of a Global Engineer (Hundley, 2013) and (ii) mathematics usage in engineering practice (Goold, 2012). Twenty competences relate to requirements of a Global Engineer and eighteen competences relate to type of mathematics required in engineering practice. Students' perceptions of engineering practice are measured by students' ratings of attributes of a global engineer. Mathematics competencies ratings are included as there are significant difference between engineers' and mathematicians' uses of mathematics (Bissell & Dillon, 2000).

Students' perceptions of engineering practice are captured both quantitatively and qualitatively. Students are required to rate the degree and to give corresponding reasons why (i) "you believe you will make a good engineer" and (ii) "you believe that your engineering education prepares you for your future career in engineering practice". To further explore students' perceptions of their preparation for engineering practice, they are requested to describe the "type of work you expect to do in your future career as a professional engineer working in engineering practice".

Data Analysis

Minitab statistical software (version 16) is used to analyse the quantitative data collected in this study. Population means are calculated with 95% probability and paired t-test is used to determine if there is a significant difference between the degree competencies are required by practising engineers and learned by students; a p-value less than 5% establishes a difference (with 95% confidence) (Reilly, 2006). The qualitative data is analysed qualitatively using a system of open coding (Miles & Huberman, 1994; Silverman, 2010).

Results

Students are generally confident that they will make good engineers; the main reasons are because they are "hardworking" and they are performing well in exams, figure 1. When asked what type of work they expect to do in future careers, "design" and "programming" are the top answers. Reasons students believe that their engineering education is good preparation for future careers in engineering practice are: (i) it covers the necessary material, (ii) there is a large workload and (iii) there is a strong practical element, figure 2.

The top 3 competencies and characteristics students believe are required by practising professional engineers are (i) an understanding of engineering, science, and mathematics fundamentals (ii) an ability to think both individually and cooperatively and (iii) effective functioning on a team. The bottom 3 competencies include (i) fluency in at least 2 languages, (ii) non-mathematical ideas and (iii) speed of calculations.

The top 3 competencies and characteristics students believe they have learned are (i) initiative and a willingness to learn, (ii) understanding of engineering, science, and mathematics fundamentals and (iii) understanding the role that mathematics plays in the world. The bottom 3 competencies include: (i) fluency in at least 2 languages, (ii) understanding the political, social, and economic perspectives and (iii) international/global perspective.

The study highlights significant differences between the degree competencies and characteristics are required by practising engineers and learned by students as evidenced by p value < 5%, Table 1.

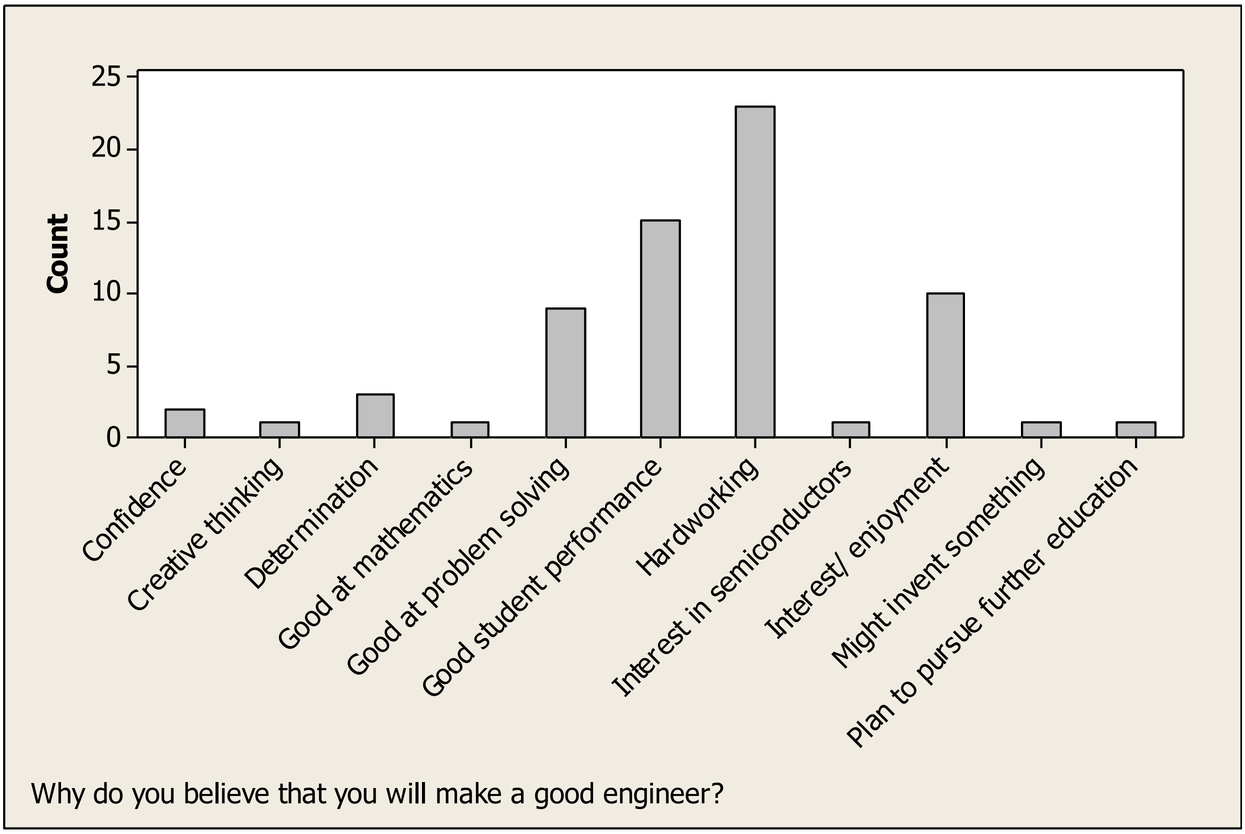

Figure 1: Reasons why students believe they will make good engineers

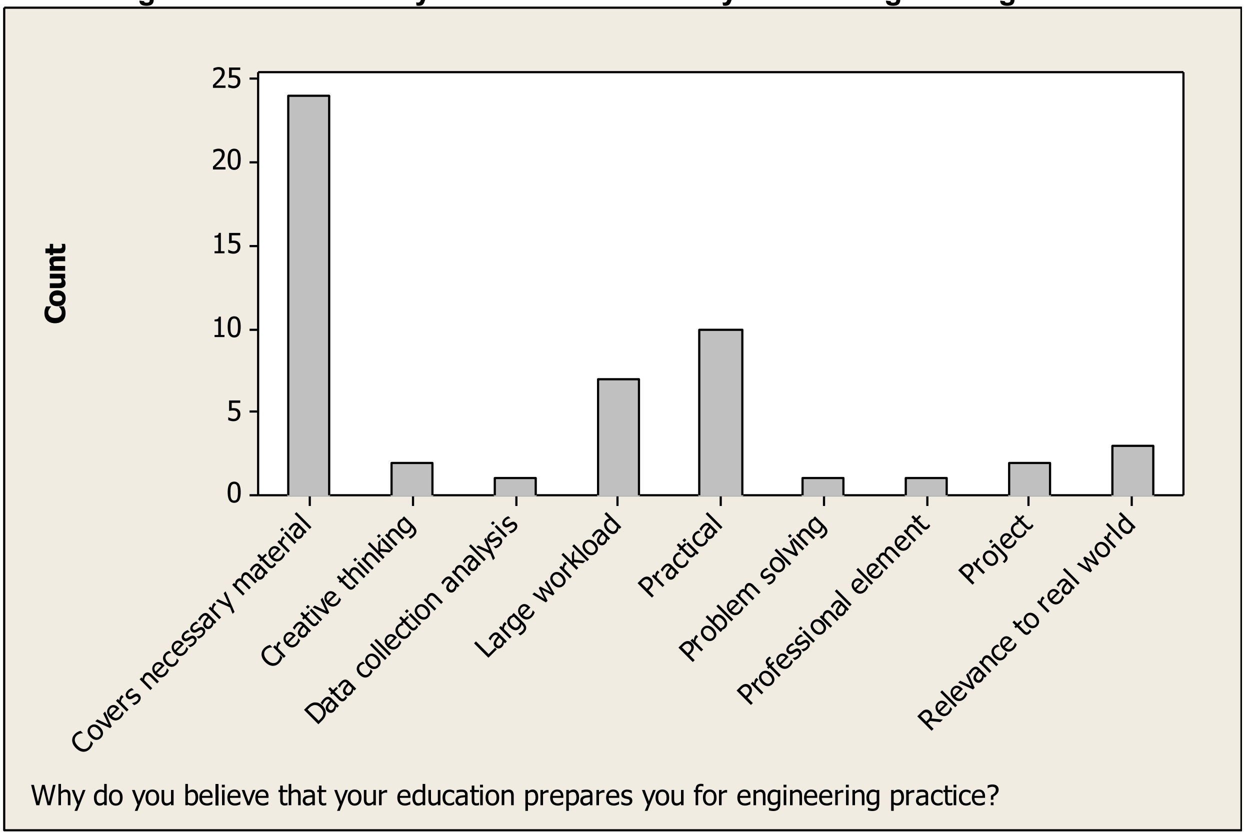

Figure 2: Reasons students believe that their engineering education is good preparation for their future careers in engineering practice

Table 1: Top differences between the degree competencies and characteristics are required by practising engineers and learned by students

Practising Engineers' Competencies and Characteristics Value scale: 1 = not at all; 2 = very little; 3 = a little; 4 = quite a lot; 5 = a very great deal	Q7: Degree required by practising engineers	Q8: Degree learned (developed competency)	difference (Q7-Q8)	P-value
international/global perspective	3.5556	2.944	0.611	0
high-level of professional competence	4.2	3.6667	0.533	0
ability to think both individually and cooperatively	4.4	3.9111	0.488	0
understanding of the ethical and business norms and applies norms effectively in a given context e.g. organisation, industry, country, etc.	3.5333	3.056	0.478	0
ability to think both critically and creatively	4.2556	3.8	0.456	0
effective functioning on a team (understands team goals, contributes effectively to team work, supports team decisions, respects team members, etc.)	4.3444	3.9	0.444	0
understanding of stages/phases of product lifecycle (design, prototyping, testing, production, distribution channels, supplier management, etc.)	4.0667	3.656	0.411	0.001
positive self-image and positive self-confidence	4.0889	3.6778	0.411	0
effective communication to both technical and non-technical audiences	3.789	3.3889	0.4	0.002
fluency in at least two languages	2.967	2.578	0.389	0.015
interdisciplinary/multidisciplinary perspective	3.8667	3.5	0.367	0.001
personal and professional judgment in effectively making decisions and managing risks	4.0222	3.6889	0.333	0.003
mathematical expectation of results from computer tools	3.9222	3.589	0.333	0.003
commitment to quality principles/standards and continuous improvement	4.144	3.8222	0.322	0.001
understanding of project planning, management and the impacts of projects on various stakeholder groups e.g. project team members, project sponsor, project client, end-users, etc.	3.8667	3.544	0.322	0.01
understanding of political, social, and economic perspectives	3.2	2.889	0.311	0.01
dealing with uncertainty and ambiguity	3.8444	3.5444	0.3	0.005

Competencies with greatest mean differences include: (i) international/global perspective (0.611), (ii) high-level of professional competence (0.533), (iii) ability to think both individually and cooperatively (0.488), (iv) understanding of the ethical and business norms and applies norms effectively in a given context e.g. organisation, industry, country, etc. (0.478), (v) ability to think both critically and creatively (0.456), (vi) effective functioning on a team (0.444), (vii) understanding of stages/phases of product lifecycle (0.411), (viii) positive self-image and positive self-confidence (0.411) and (ix) effective communication to both technical and non-technical audiences (0.4). The results show that there are significant mean differences for fifteen of the twenty attributes required by a Global Engineer (Hundley, 2013). There are no significant differences between Irish and Chinese students' results.

It is noted that, for all competencies, the degree competencies are required by practising engineers exceed the degree students have learned these competencies; it is interpreted that students do not perceive any of their engineering education as unnecessary.

Discussion

Students' initiative and willingness to learn is very evident in this study. Students are generally confident that they will make good engineers because they work hard and their education covers the standard necessary engineering material. However the type of work students expect to do in their future career is vague. There is evidence from the data that students' learning is based solely on the academic viewpoint, for example students believe that good examination performance underlies good professional performance. However there is no evidence of expected career paths. This suggests that engineering is a diffuse professional field where students have "unclear expectations about their transition from study to working life" (Reid & Petocz, 2013).

While students rate understanding of engineering, science, and mathematics fundamentals highly in both the list of competencies required by practising engineers and the list of competencies they have developed, students perceive gaps in their preparation for professional practice. Fifteen of the twenty competencies required by a Global Engineer show significant differences between the degree competencies and characteristics are required by practising engineers and learned by students compared to just two of the eighteen mathematics in engineering practice competencies. In particular students' global, professional, thinking, ethical, business, teamwork, confidence and communications skills are inadequate. This suggests that while professional practice has evolved into a multidisciplinary profession, the applied engineering sciences still dominate the undergraduate curriculum at the expense of tacit knowledge, political, social, and economic perspectives and an ability to achieve practical results through other people.

While students place non-mathematical ideas in the bottom three competencies and characteristics required by practising professional engineers, the perceived gaps between practice and learning are also evident for the "subjective" mathematics competencies; these are mathematical expectation of results from computer tools and dealing with uncertainty and ambiguity. The dominance of students' "objective" engineering, science, and mathematics learning compared to "subjective" learning is evident. This is a shortcoming of engineering education; a study of practising engineers found that focusing on "objective" solutions at the expense of "subjective analysis" contributes to engineer's poor communication skills and reduces the value of mathematics in engineering practice thus creating an affective hurdle for graduate engineers to overcome when they begin working as engineers (Goold, 2012).

This study contributes to the knowledge about the gap between engineering education and engineering practice where many graduate engineers are challenged by the transition into engineering practice (Trevelyan, 2010a). It is concluded that there is a need to make professional engineering clearer; the mismatch between engineering education and practice could be reduced by incorporating real life engineering experiences into engineering education. Another implication for engineering education is the weakness of the curriculum in the context of competencies required by a Global Engineer. The findings challenge engineering educators to include more subjective analysis, technical communicating skills and insights into engineering practice in the undergraduate curriculum. In addition to practitioners engaging in technical work, students should learn about the skills, knowledge and competencies required by Global Engineers. (Brunhaver, Gilmartin, Grau, Sheppard, & Chen, 2013). This in turn would improve engineering students' learning and engagement with their studies (Wigfield & Eccles, 2002). Following from this study, the benefits of a portfolio of engineering practice, illustrating the practical realities of modern engineering practice, to first year electronic engineering students at ITTD is currently being investigated

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